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Stuebe

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(54) **TISSUE FUSION SYSTEM AND METHOD OF PERFORMING A FUNCTIONAL VERIFICATION TEST**

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A61B 18/00	(2006.01)
A61B 18/10	(2006.01)

(52) **U.S. Cl.**

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USPC **606/31**; 606/34

(58) **Field of Classification Search**

CPC A61B 18/04; A61B 18/08; A61B 18/082; A61B 18/085; A61B 18/1442; A61B 18/1445; A61B 18/1447; A61B 2018/00827; A61B 2018/00648; A61B 2018/00654; A61B 2018/00892

USPC 606/33, 34, 41, 50–52

See application file for complete search history.

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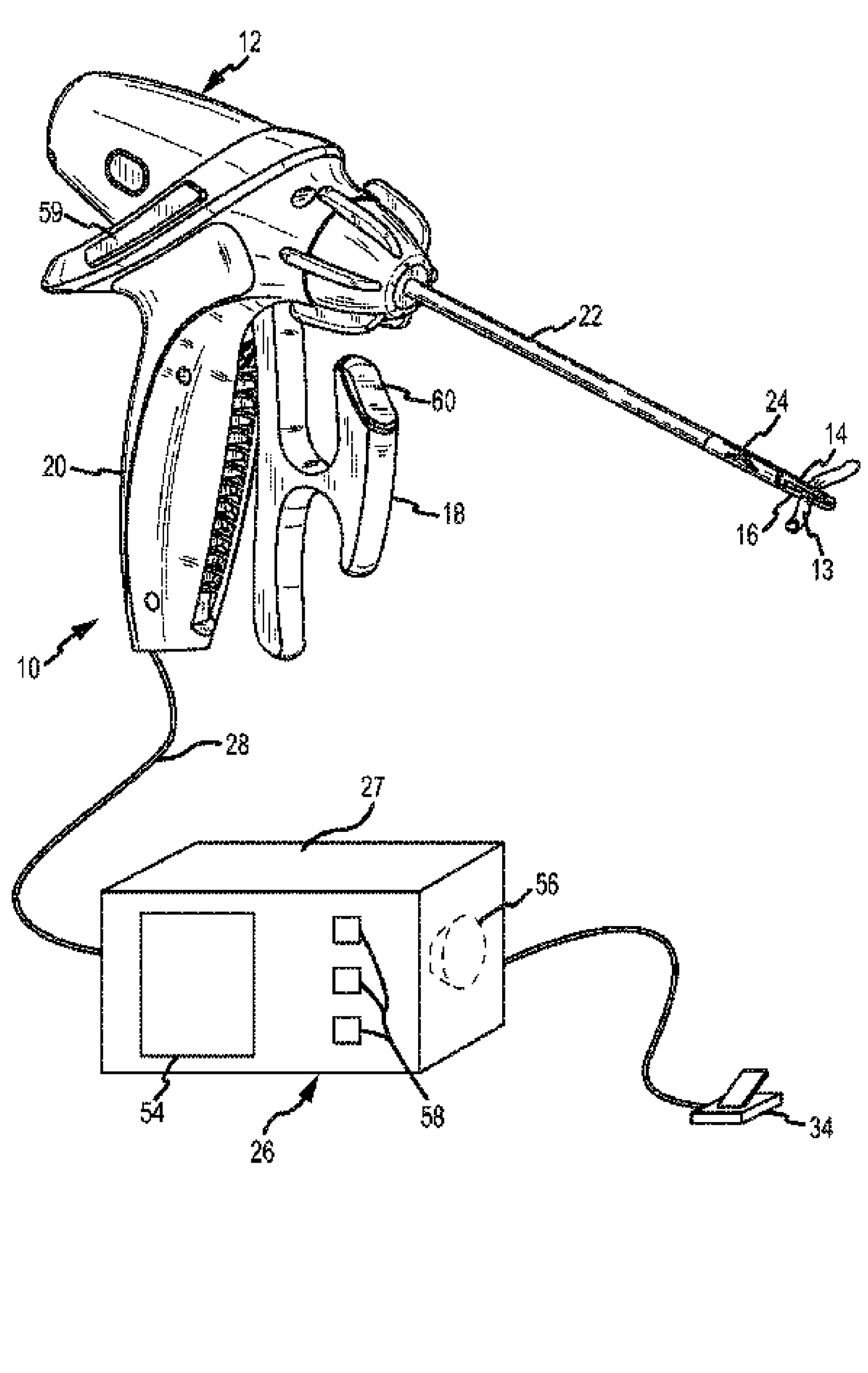
Primary Examiner — Michael Peffley
Assistant Examiner — Khadijeh Vahdat

(57) **ABSTRACT**

A jaw heating element of a handpiece of a thermal tissue operating system is tested on an ongoing basis by supplying a test heater power signal to the jaw heating element between individual thermal tissue operations. Voltage and current through the jaw heating element is sensed and the resistance of the jaw heating element is calculated. If the calculated resistance is outside a range of predetermined acceptable values, an error condition is indicated.

3 Claims, 8 Drawing Sheets



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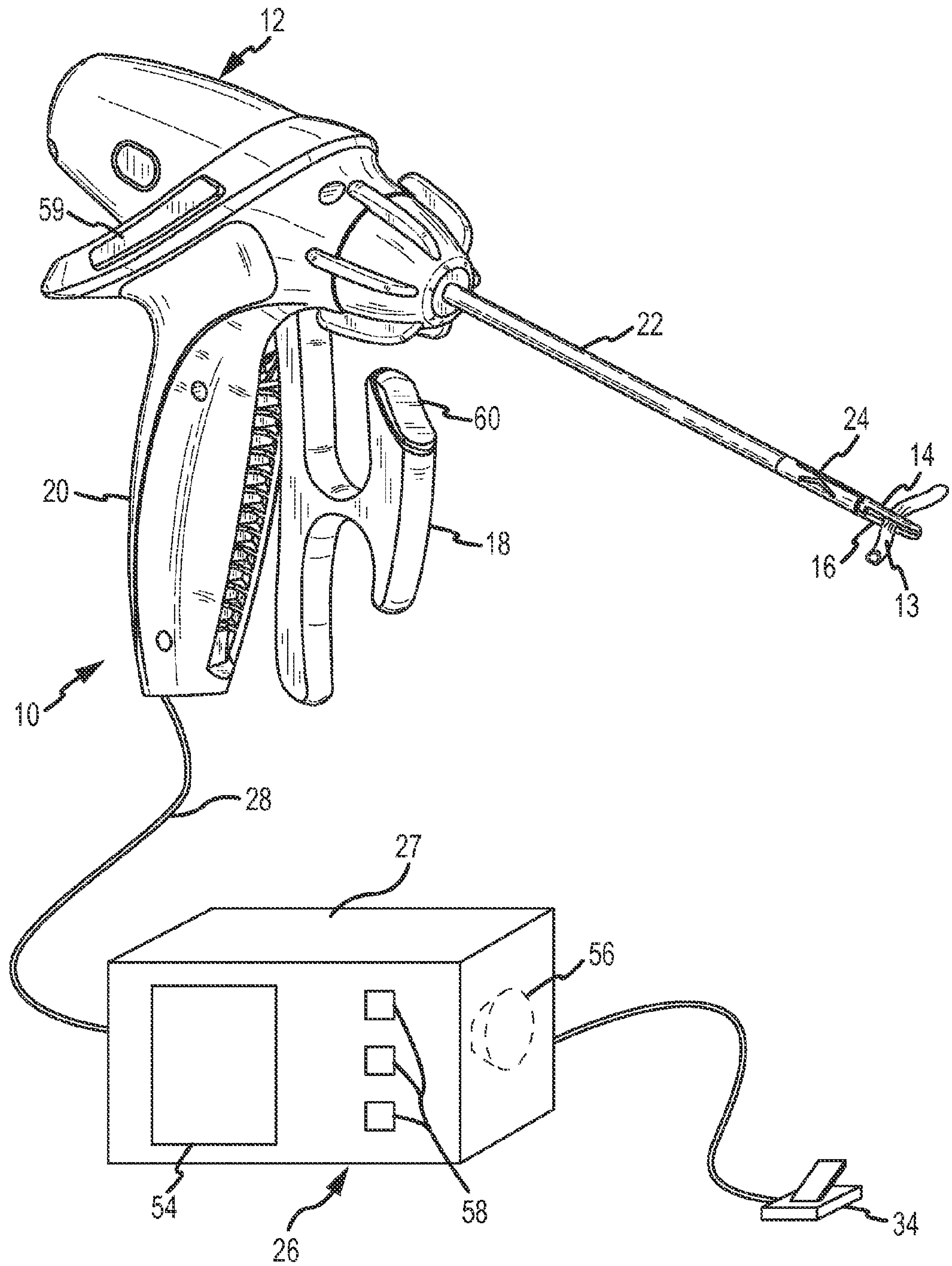


FIG.1

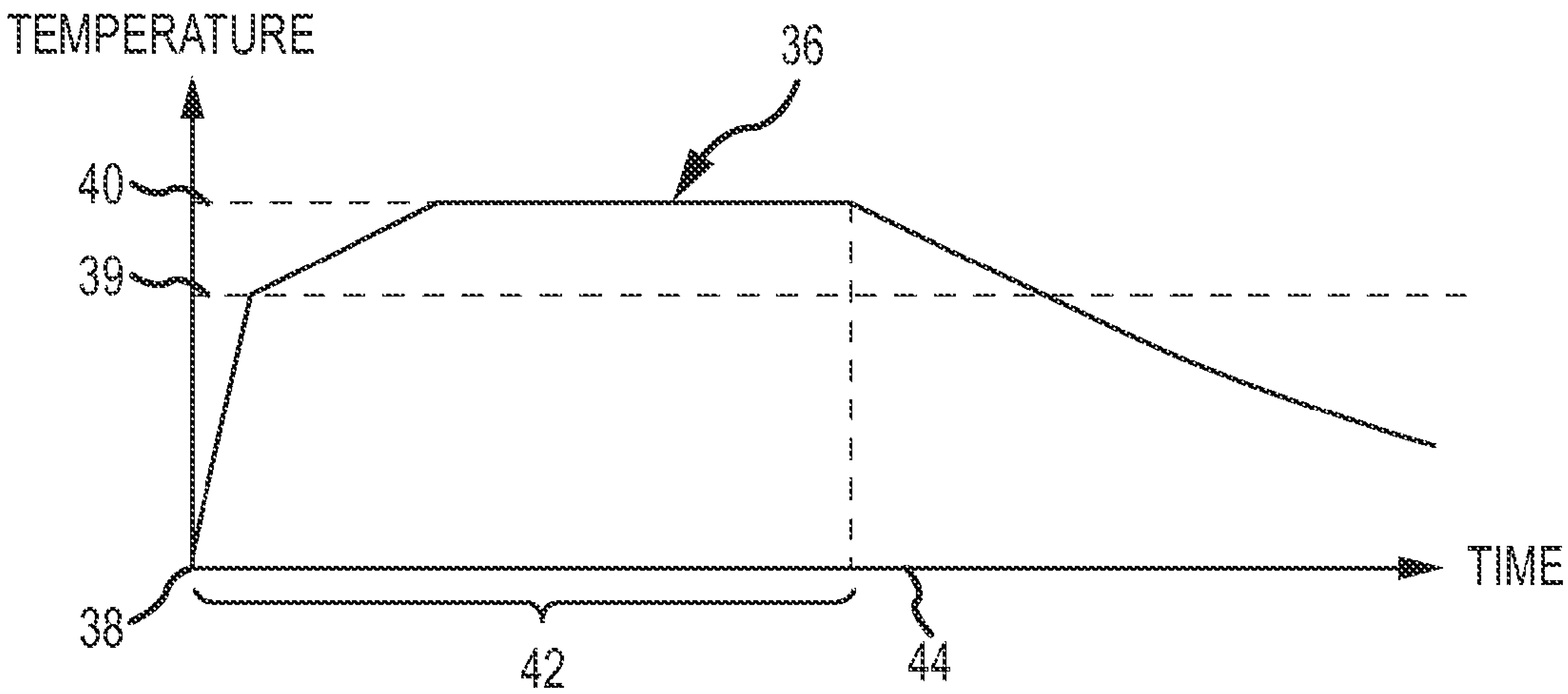
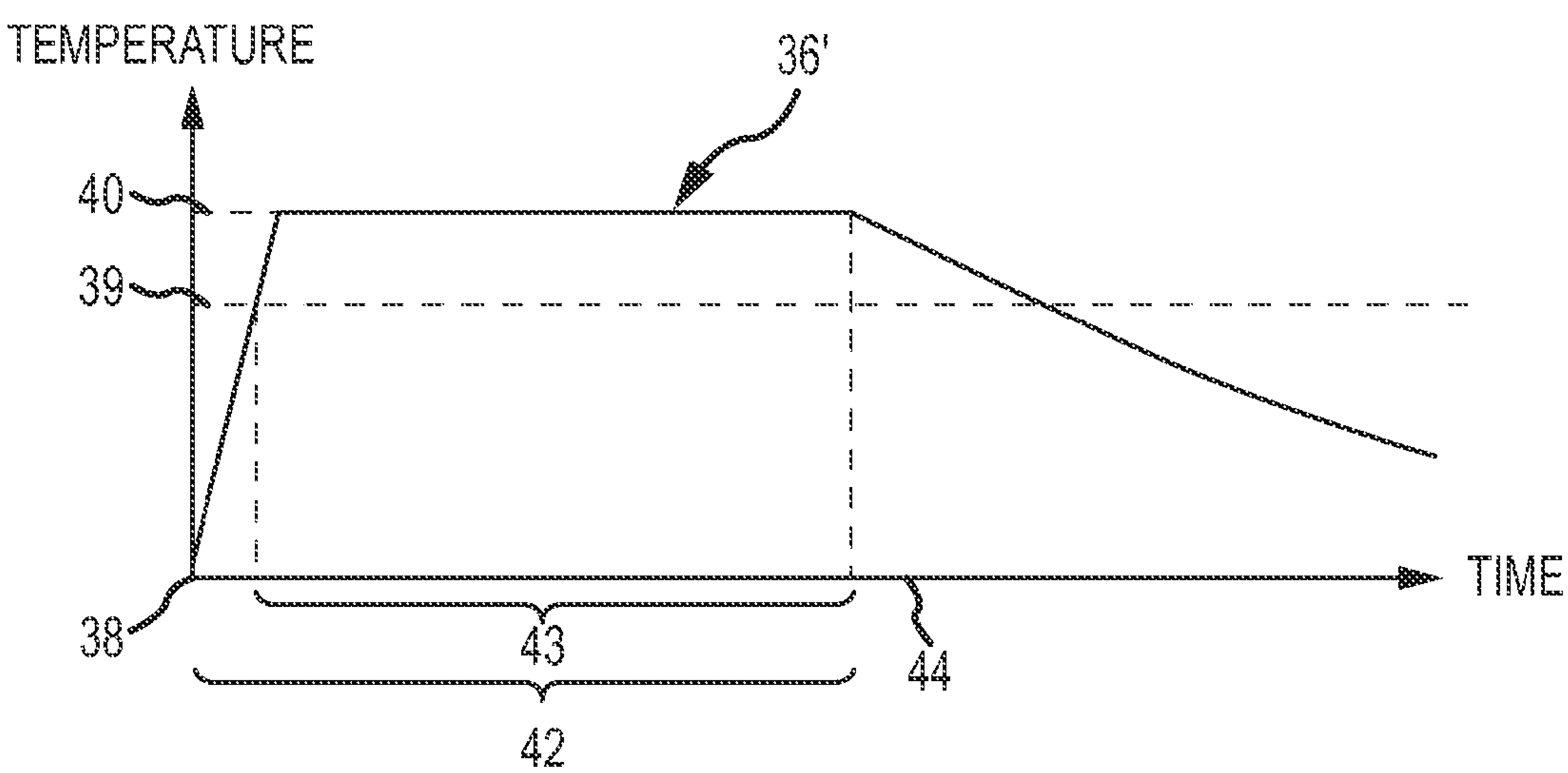

TEMPERATURE
36
40
39
TIME
38
42
44

FIG.2A


TEMPERATURE
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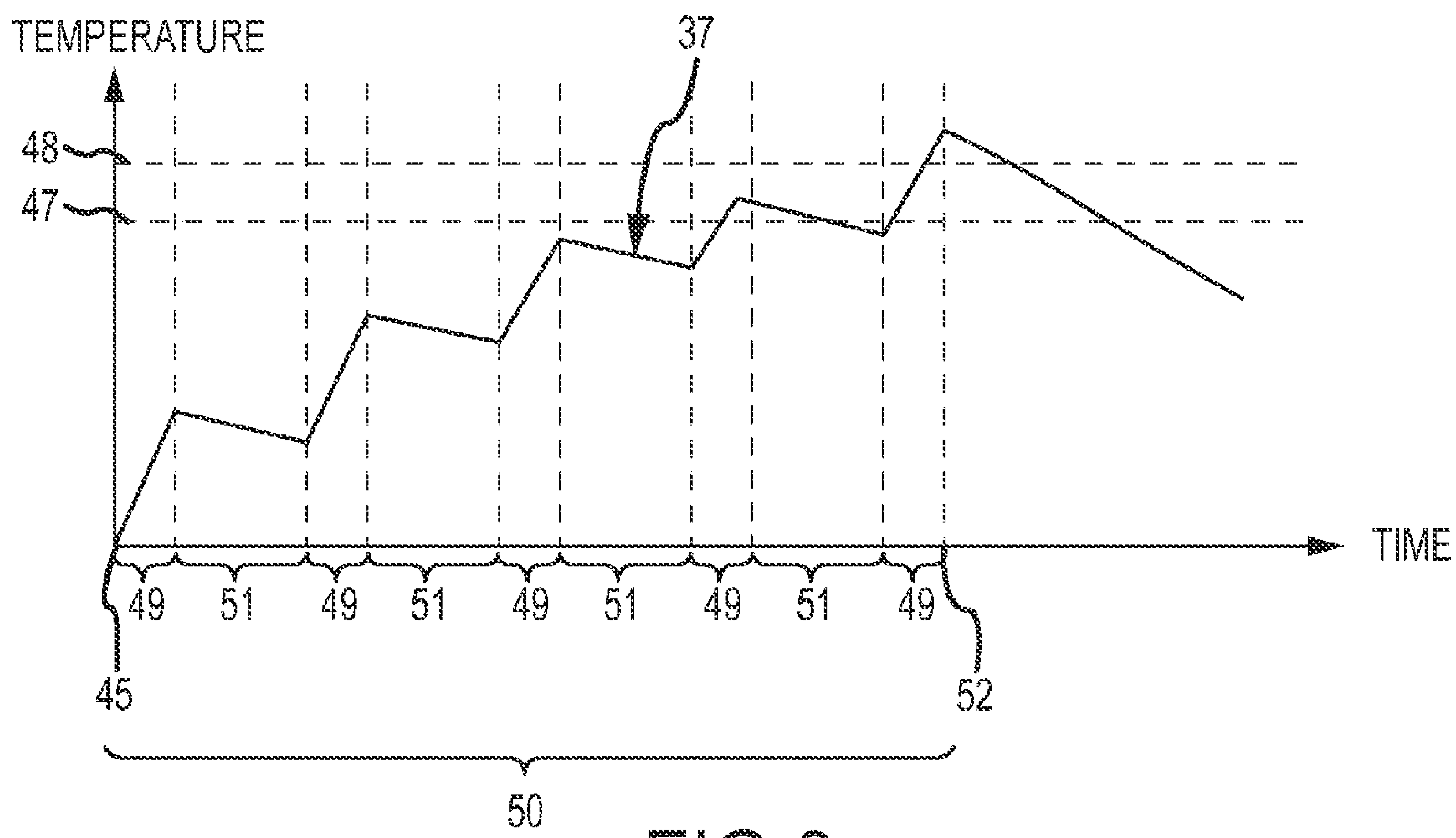
39
TIME
38
43
44
42

FIG.2B


TEMPERATURE
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48
47
TIME
49
51
49
51
49
51
49
51
49
45
52
50

FIG.3

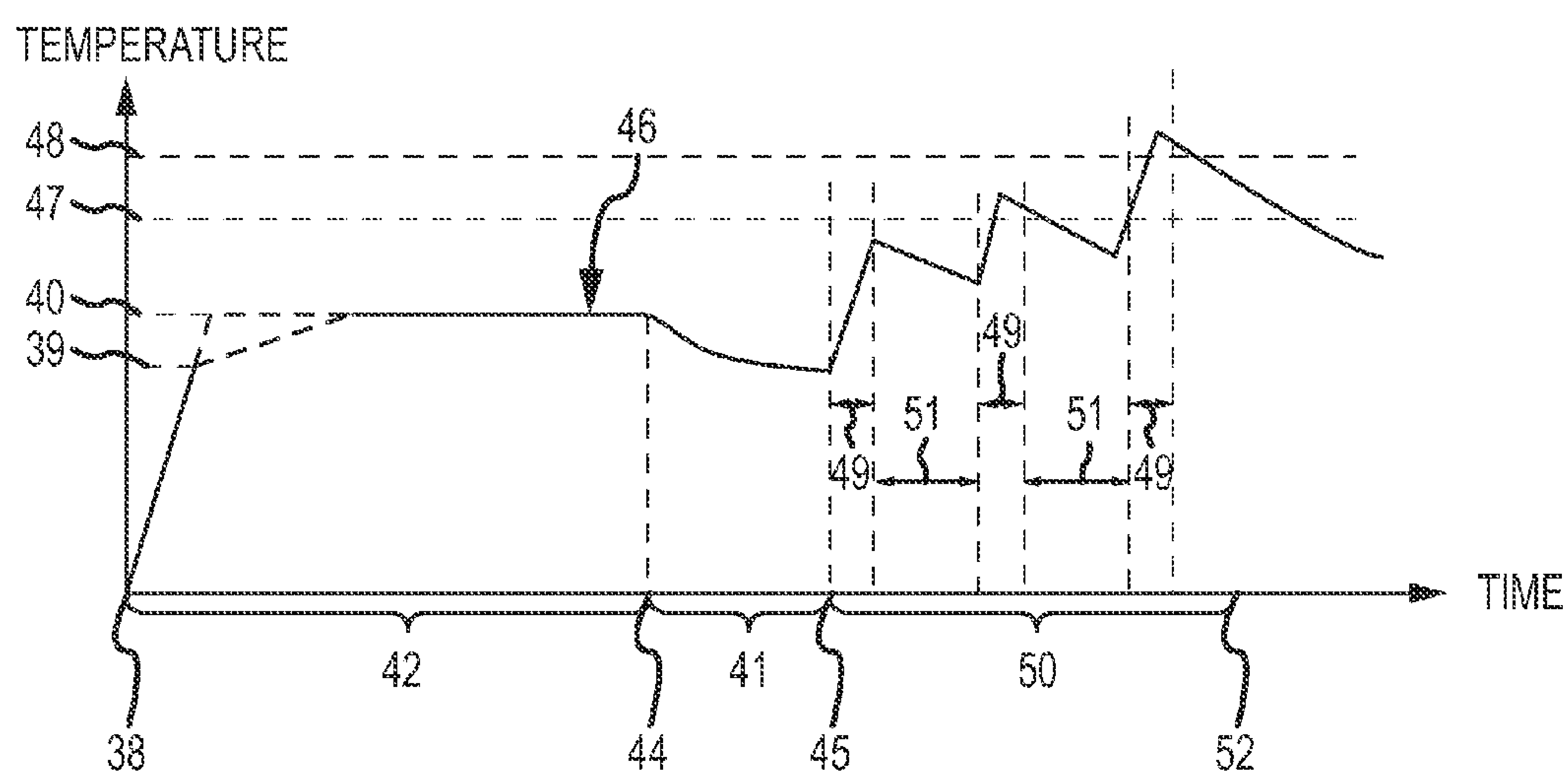
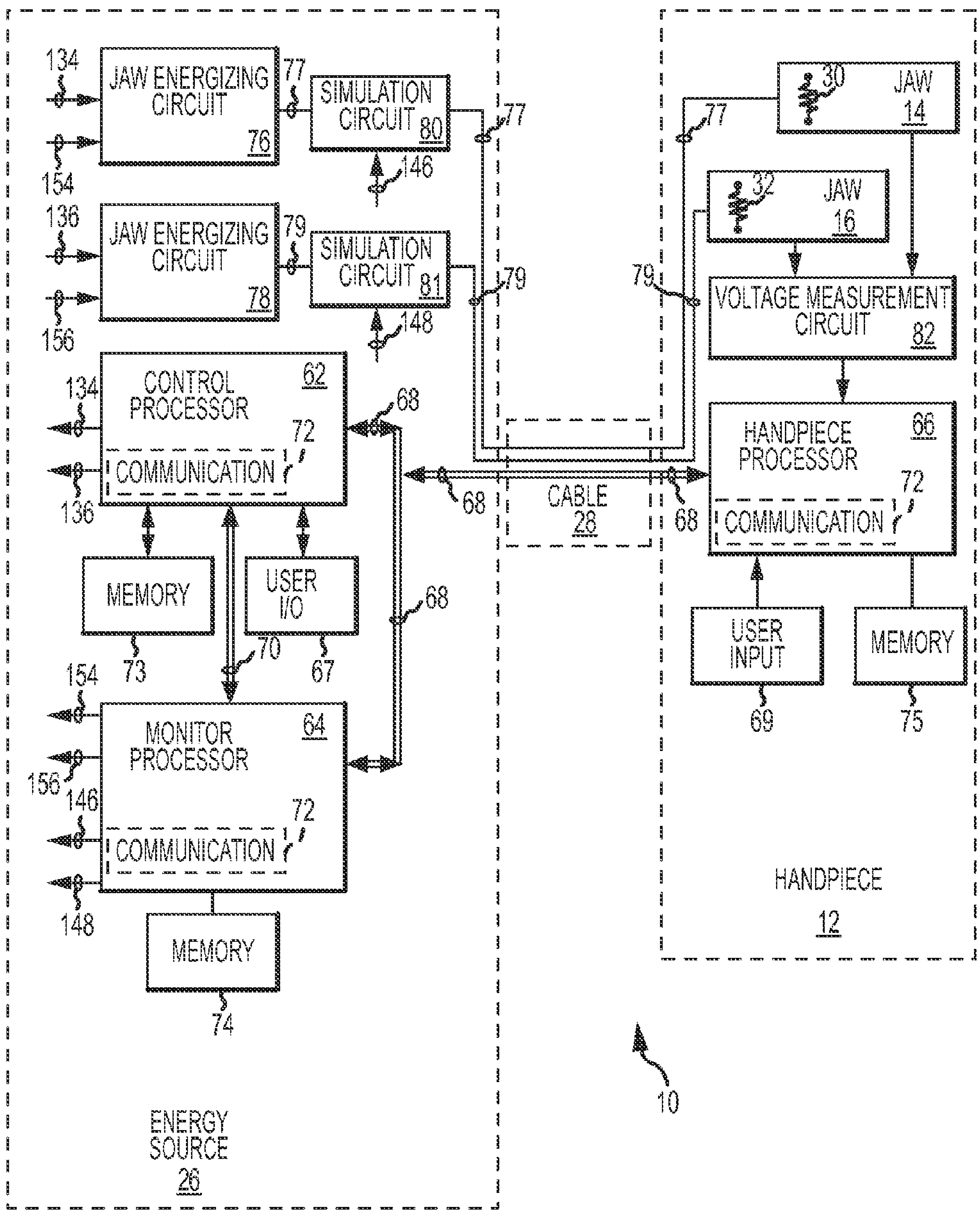

TEMPERATURE
46
48
47
40
39
49
51
51
49
49
TIME
42
41
50
38
44
45
52

FIG.4



134
JAW ENERGIZING CIRCUIT 76
154
77
SIMULATION CIRCUIT 80
146
77
136
JAW ENERGIZING CIRCUIT 78
156
79
SIMULATION CIRCUIT 81
148
79
134
CONTROL PROCESSOR 62
72
COMMUNICATION
136
68
MEMORY
73
USER I/O
67
70
68
154
MONITOR PROCESSOR 64
156
146
72
COMMUNICATION
148
MEMORY
74
ENERGY SOURCE 26
CABLE 28
68
68
77
30
JAW 14
32
JAW 16
79
VOLTAGE MEASUREMENT CIRCUIT 82
HANDPIECE PROCESSOR 66
72
COMMUNICATION
USER INPUT
69
MEMORY
75
HANDPIECE 12
10

FIG.5

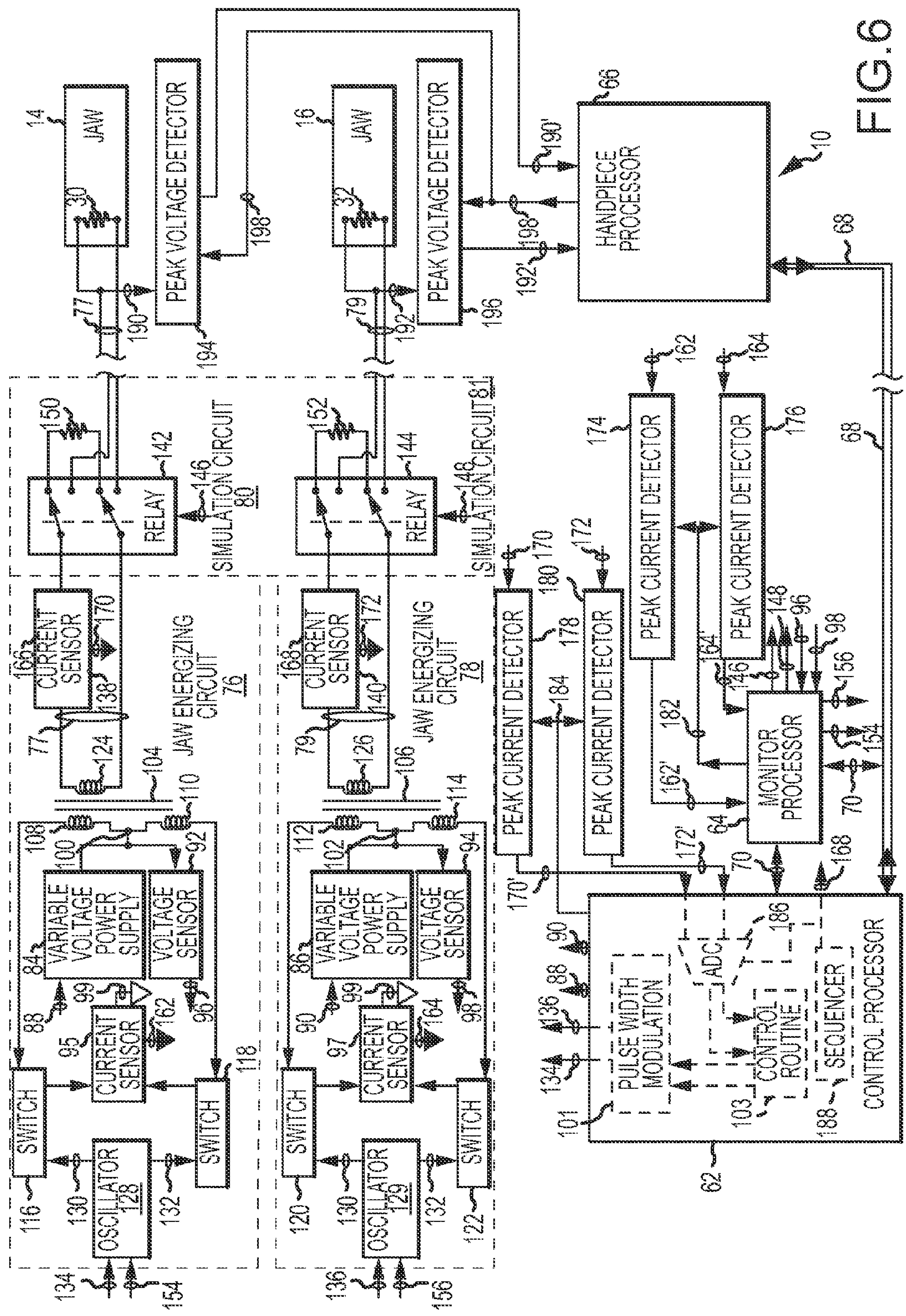

JAW
PEAK VOLTAGE DETECTOR
JAW
PEAK VOLTAGE DETECTOR
HANDPIECE PROCESSOR
RELAY
SIMULATION CIRCUIT 80
RELAY
SIMULATION CIRCUIT 81
PEAK CURRENT DETECTOR
PEAK CURRENT DETECTOR
CURRENT SENSOR
JAW ENERGIZING CIRCUIT 76
CURRENT SENSOR
JAW ENERGIZING CIRCUIT 78
PEAK CURRENT DETECTOR
PEAK CURRENT DETECTOR
MONITOR PROCESSOR
VARIABLE VOLTAGE POWER SUPPLY
VOLTAGE SENSOR
VARIABLE VOLTAGE POWER SUPPLY
VOLTAGE SENSOR
SWITCH
CURRENT SENSOR
SWITCH
OSCILLATOR 128
SWITCH
CURRENT SENSOR
SWITCH
OSCILLATOR 129
PULSE WIDTH MODULATION
ADC
CONTROL ROUTINE
SEQUENCER
CONTROL PROCESSOR

FIG.6

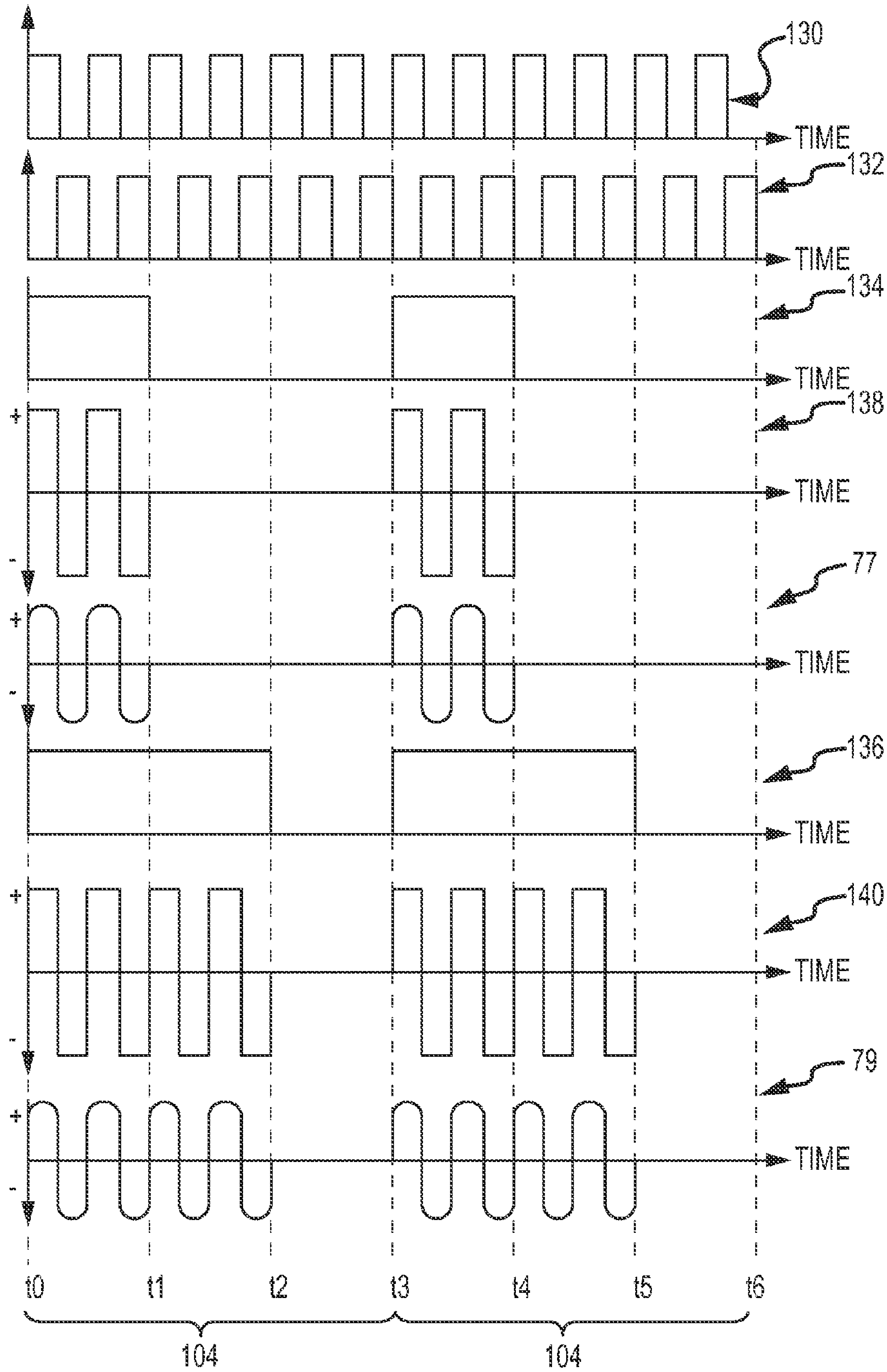


FIG.7A

FIG.7B

FIG.7C

FIG.7D

FIG.7E

FIG.7F

FIG.7G

FIG.7H

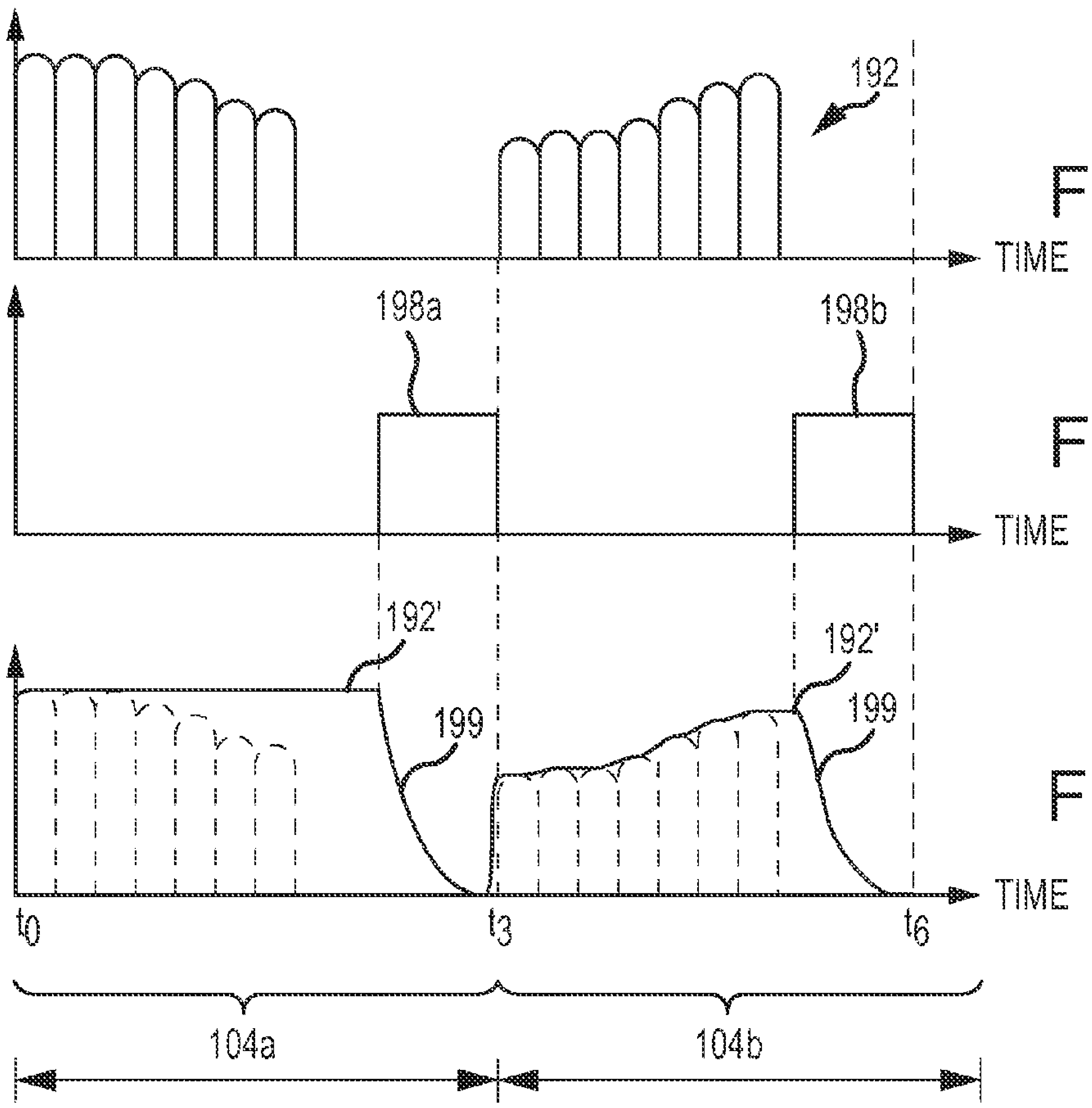


FIG.8A

FIG.8B

FIG.8C

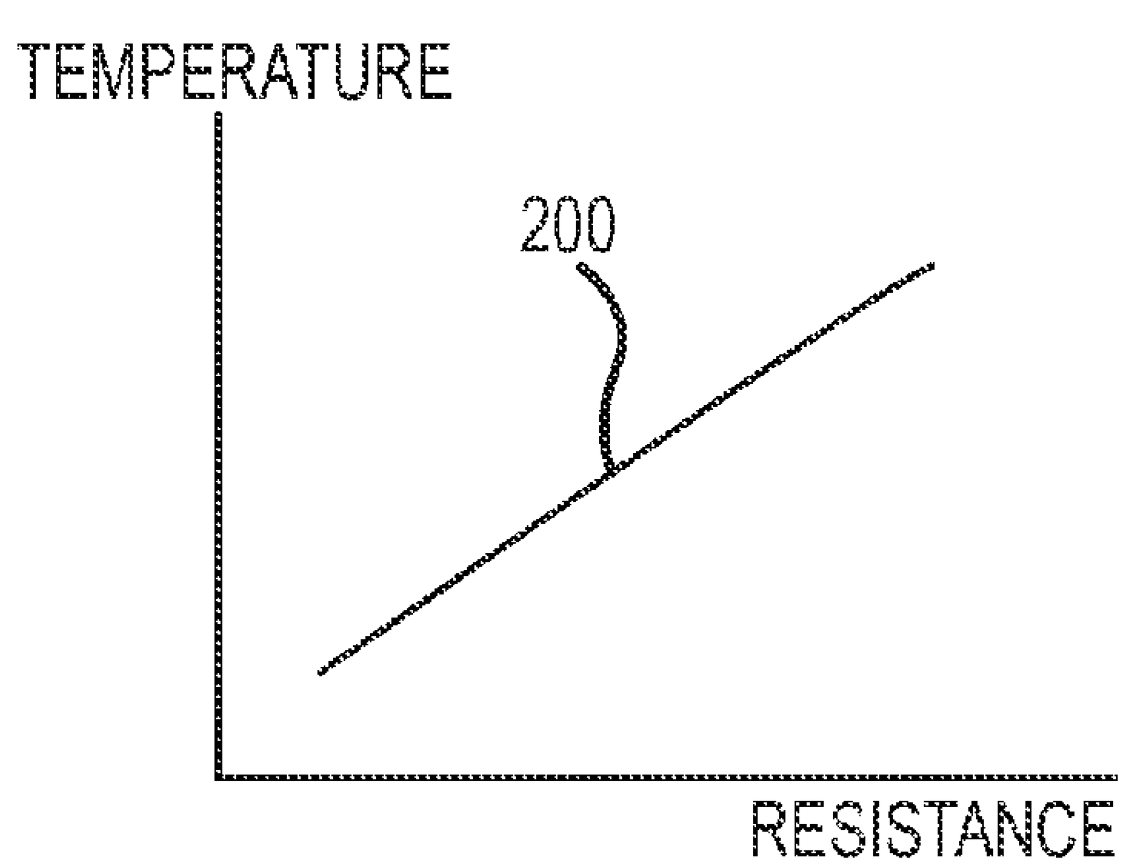


FIG.9

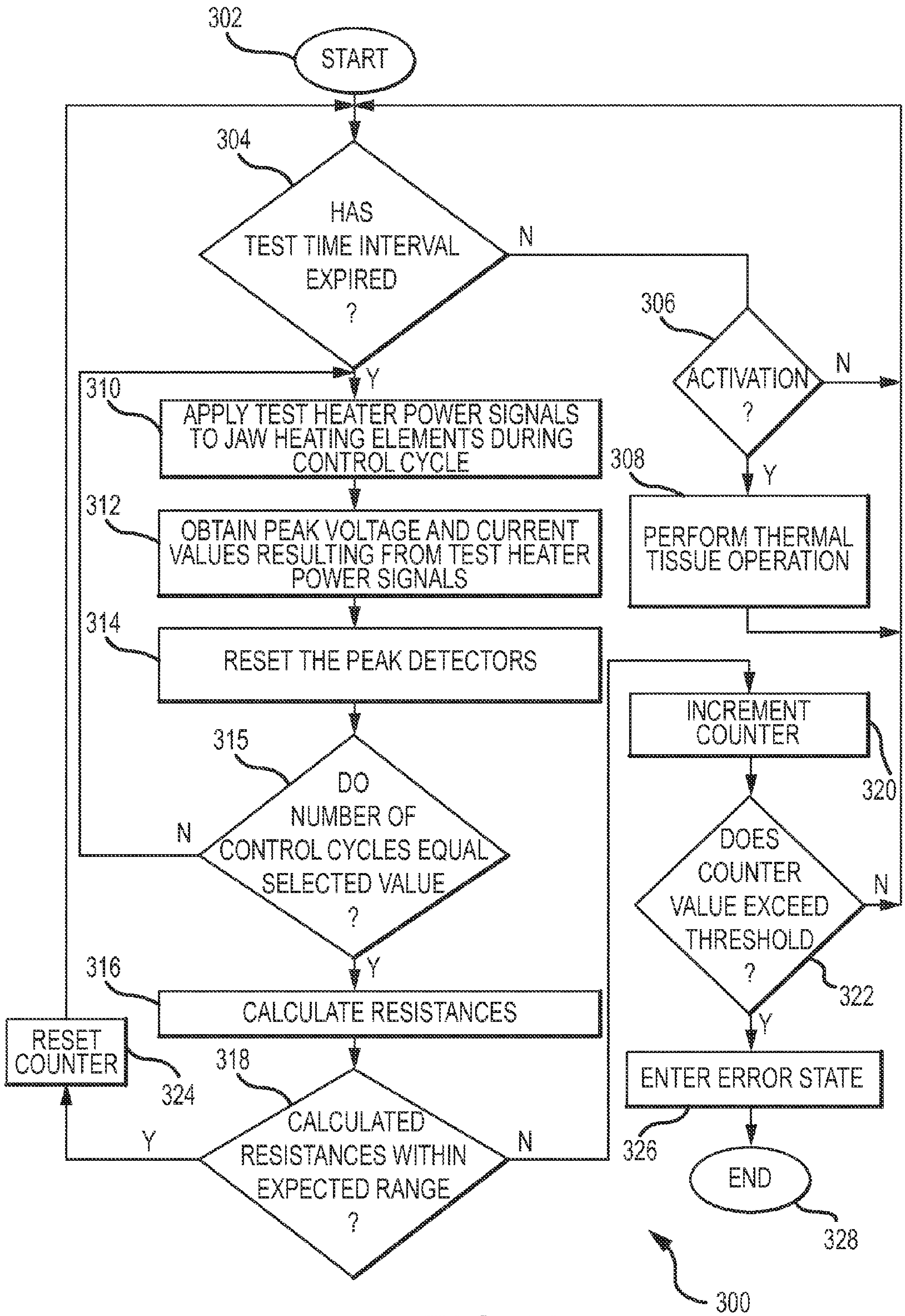

302
START
304
HAS TEST TIME INTERVAL EXPIRED ?
N
Y
306
ACTIVATION ?
N
Y
308
PERFORM THERMAL TISSUE OPERATION
310
APPLY TEST HEATER POWER SIGNALS TO JAW HEATING ELEMENTS DURING CONTROL CYCLE
312
OBTAIN PEAK VOLTAGE AND CURRENT VALUES RESULTING FROM TEST HEATER POWER SIGNALS
314
RESET THE PEAK DETECTORS
315
DO NUMBER OF CONTROL CYCLES EQUAL SELECTED VALUE ?
N
Y
316
CALCULATE RESISTANCES
318
CALCULATED RESISTANCES WITHIN EXPECTED RANGE ?
Y
N
RESET COUNTER
324
INCREMENT COUNTER
320
DOES COUNTER VALUE EXCEED THRESHOLD ?
N
Y
322
ENTER ERROR STATE
326
END
328
300

FIG.10

TISSUE FUSION SYSTEM AND METHOD OF PERFORMING A FUNCTIONAL VERIFICATION TEST

CROSS REFERENCE TO RELATED INVENTIONS

This invention is related to those inventions described in U.S. patent application Ser. No. 12/842,327 filed Jul. 23, 2010, titled Jaw Movement Mechanism and Method for Surgical Tool, and U.S. patent application Ser No. 12/842,399 filed Jul. 23, 2010, titled Surgical Tool and Method Using Crossbar Lever, and U.S. patent application Ser No. 12/842,606 filed Jul. 23, 2010, titled Tissue Fusion System and Method for Performing a Self Test, all of which are filed concurrently herewith and all of which are assigned to the assignee hereof. The subject matter of these applications is incorporated herein by this reference.

FIELD OF THE INVENTION

This invention relates to a thermal tissue operating system, which is also referred to generically as a tissue fusion system. More particularly, the present invention relates to a new and improved functional verification test in which jaw heating elements of a handpiece of the thermal tissue operating system are tested on a continuous basis during multiple, sequentially-occurring thermal tissue operations to identify potential problems and verify proper operation while the system is in use during a surgical procedure.

BACKGROUND OF THE INVENTION

A thermal tissue operation involves simultaneously compressing and heating tissue to seal together pieces of tissue, to cut a single piece of tissue into separate parts, or to sequentially seal pieces of tissue and then cut the sealed tissue. Tissue cutting occurs in the same manner as tissue sealing, except that additional energy and heat are applied to the tissue to cause it to sever. Typical thermal tissue operations involve sealing blood vessels during surgery to prevent bleeding and blood loss. Sealing a blood vessel before severing it between spaced apart sealed locations or in the middle of single sealed location completely avoids blood loss.

A thermal tissue operating system includes a handpiece which is connected to an energy source. The handpiece has a pair of opposing jaws between which the tissue is mechanically compressed. Electrical power from the energy source is converted to thermal heat energy in at least one of the opposing jaws, and the heat is conducted into the compressed tissue. The characteristics of the electrical energy applied to the jaws control the characteristics of the heat energy conducted into the jaws. The characteristics of the thermal energy transferred to the tissue and the time during which the thermal energy is transferred constitute an individual thermal tissue operation, i.e. a tissue sealing operation, a tissue cutting operation, or a combined tissue cutting and sealing operation. Usually, the entire surgical procedure is completed by performing many separate individual thermal tissue operations.

A thermal tissue operating system can be subject to a number of external influences, such as accidental mishandling and improper use, for example. Such external influences have the potential to adversely affect the proper operation of the system. A malfunctioning or improperly functioning system may inadequately seal tissue, inadequately cut tissue, inadequately seal and cut the tissue, and otherwise complicate the surgical procedure.

The jaw heating elements are subject to especially rigorous operating conditions. The jaw heating elements must conduct relatively high electrical current, must withstand rapidly increasing temperatures, must efficiently transfer thermal energy to the compressed tissue, and must maintain high temperature during the thermal tissue operation, among other things. When the thermal tissue operation is completed and electrical current is no longer conducted, the jaw heating elements undergo rapid cooling. The substantial changes in the electrical current conducted and the rapid increases and decreases in temperature impose significant stresses on the resistive material of the jaw heating elements and on the material surrounding the resistive material and on the adjoining structures and materials which support the jaw heating elements.

The cyclic nature of the energy application during repeated thermal tissue operations performed during the surgical procedure creates a practical limitation on the number of times that the heating elements will perform satisfactorily. For example, repeated use can cause the resistive material to undergo changes in properties or to develop areas of reduced or increased conductivity, resulting in changes in the resistance and thermal response characteristics of the jaw heating elements. As another example, an exaggerated temperature might melt the electrical connections to the jaw heating elements or even melt parts of the jaw heating elements or their supporting structures. Such adverse circumstances might cause an open circuit or short circuit condition to occur. Of course an open circuit prevents the jaw heating elements from conducting current and creating thermal energy. A short circuit might cause electrical current to flow into portions of the handpiece where it is not intended and could overload and therefore damage the energy source of the thermal tissue operating system.

A typical thermal tissue operating system employs feedback to regulate the amount of energy supplied to the jaw heating elements, thereby assuring that a desired temperature is applied or a desired amount of energy is transferred to the tissue compressed between the jaws. If the resistance of the jaw heating elements changes or if the current flow path to the heating elements changes in such a way to prevent or limit the maximum amount of current delivered to the jaw heating elements, the ability to regulate the temperature of the tissue compressed between the jaws will be impaired. Of course, impaired temperature regulation leads to degradation of the thermal tissue operation, because an insufficient or excessive amount of thermal energy will be applied to the compressed tissue.

In some cases where less than the desired amount of thermal energy is applied to the compressed tissue, it can be difficult or impossible for the surgeon to recognize that the thermal effect on the tissue is inadequate. For example, in the case of a vessel which carries blood or other body fluid, an attempt to seal the vessel with a moderately inadequate amount of thermal energy may create an effect which appears to the surgeon to be a sound tissue seal. The tissue effect may even withstand internal bodily blood or fluid pressure for some short amount of time, before beginning to leak or rupturing. The resulting internal bleeding or fluid loss will then require a resealing thermal tissue operation. If the resealing operation is performed during the course of the surgical procedure, the time to do so prolongs the entire surgical procedure and subjects the patient to additional trauma. If the internal bleeding or fluid loss is discovered after the initial surgical procedure has been completed, a second surgical procedure must be performed to gain access to the leak and seal it. Performing a second surgical procedure on the patient adds substantially to the trauma that the patient has already experienced.

It is desirable to identify potential problems with a thermal tissue operating system before it is used in the surgical procedure. The early identification of problems has the potential to avoid many significant subsequent complications. The invention of the above-referenced application Ser. No. 12/842,606 involves a number of self tests which the thermal tissue operating system performs on itself, preferably upon initial start-up or powering-on of the system. These self tests are very useful for identifying a number of different, potential problems which manifest themselves before the thermal tissue operating system is used during a surgical procedure. However, many of the initial start-up or power-on tests are performed only once before commencing a surgical procedure. The surgical procedure could continue for many hours, during which other problems might arise from repeated use of the thermal tissue operating system during the course of the surgical procedure.

SUMMARY OF THE INVENTION

It is desirable to identify potential problems with a thermal tissue operating system that might develop as a result of ongoing use of the system during a surgical procedure. An early identification of any problem avoids subsequent surgical complications and reduces the trauma on the patient caused by prolonging the initial surgical procedure or by performing subsequent surgical procedure to correct an inadequate thermal tissue operation performed during the prior surgical procedure.

The present invention relates to a functional verification test which is performed on an ongoing basis, between thermal tissue operations conducted during the course of the entire surgical procedure, to detect potential problems in the performance of the thermal tissue operating system which might arise due to ongoing use during the course of its use in the procedure. Specifically, an ongoing functional verification test described herein recognizes the possibility of changes occurring in the jaw heating elements during the course of the procedure and that those changes may limit or inhibit the ability to perform reliable thermal tissue operations as intended. The functional verification test reduces the chances that a problem related to the jaw heating elements will go unnoticed during some part of the surgical procedure.

A relatively small amount of power from an energy source is applied to a jaw heating element during a test interval between individual thermal tissue operations. The test intervals are repeated throughout the surgical procedure. The electrical response characteristics of the jaw heating elements are measured and used to evaluate the integrity and functionality of the resistive heating elements of the jaws. In addition, the operational characteristics of the energy source of the thermal tissue operating system may also be evaluated to determine whether the energy source is functioning as expected.

In accordance with these and other considerations, this invention relates to a thermal tissue operating system for performing thermal tissue operations includes an energy source and a handpiece connected to the energy source. The handpiece includes a pair of opposing jaws which compress tissue during the thermal tissue operation. At least one of the jaws includes a jaw heating element for converting electrical power to thermal heat energy that is applied to the compressed tissue. The energy source supplies a heater power signal to the jaw heating element during the thermal tissue operation. The energy source further comprises a controller which controls the heater power signal supplied to the jaw heating element, a voltage sensor connected to the controller and operative to sense the voltage of the heater power signal supplied to the jaw heating element and to supply a voltage sense signal related to the sensed voltage of the heater power signal, a current sensor connected to the controller and operative to sense the current of the heater power signal supplied to the jaw heating element and to supply a current sense signal related to the sensed current of the heater power signal. The controller responds to the voltage sense signal and the current sense signal to calculate a resistance value of the jaw heating element, to compare the calculated resistance value to a predetermined range of expected resistance values of the heating element, and to signal an error state and to terminate delivery of the heater power signal to the jaw heating element upon the calculated resistance value falling outside of the predetermined range of expected resistance values.

In addition, this invention relates to a method of performing a functional verification test of a thermal tissue operating system which includes an energy source which produces electrical power and a handpiece which connects to the energy source. The handpiece includes a pair of opposing jaws which compress tissue during a thermal tissue operation. At least one of the jaws includes a jaw heating element for converting electrical power into thermal heat energy applied to the compressed tissue during the thermal tissue operation. The method comprises supplying a test heater power signal to the jaw heating element during test intervals when the energy source is not energizing the jaw heating element in a thermal tissue operation, sensing the current and the voltage of the test heater power signal, calculating a resistance value of the jaw heating element from the sensed current and voltage, referencing a range of expected resistance values of the jaw heating element which indicate normal characteristics of the jaw heating element, comparing the calculated resistance value with the range of expected resistance values, and communicating an error message when the calculated resistance value is outside of the range of expected resistance values.

Subsidiary features of the invention involve some or all of the following: supplying the test heater power signal at a lesser amount of power compared to the amount of power supplied in an operational heater power signal that is used to perform a thermal tissue operation; establishing each test interval to have the same time duration; creating a relatively greater duty cycle for the heater power signal during a thermal tissue operation and a relatively lesser duty cycle for the test heater power signal; calculating the resistance value of the jaw heating element from a peak voltage signal and a peak current signal created by the test heater power signal; and comparing the calculated resistance value to the predetermined range of expected resistance values during each test interval.

A more complete appreciation of the features of the present invention and its scope may be obtained from the accompanying drawings, which are briefly summarized below, from the following detailed description of a presently preferred embodiment of the invention, and from the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a perspective view of a handpiece and an energy source of a thermal tissue operating system which incorporates the present invention.

FIGS. **2**A and **2**B are graphs showing temperature versus time profiles for two different tissue sealing operations performed by the use of the thermal tissue operating system shown in FIG. **1**.

FIG. **3** is a graph showing a temperature versus time profile for a tissue cutting operation performed by the use of the thermal tissue operating system shown in FIG. **1**.

FIG. **4** is a graph showing a temperature versus time profile for a combined tissue sealing and cutting operation performed by use of the thermal tissue operating system shown in FIG. **1**.

FIG. **5** is a block diagram of certain electrical components of the energy source and the handpiece shown in FIG. **1**.

FIG. **6** is a more detailed block and schematic diagram of the energy source and handpiece shown in FIG. **5**.

FIGS. **7**A-**7**H are graphs of exemplary signals in the energy source shown in FIG. **6**, all of which share a common time axis. Specifically for two sequential control cycles, FIGS. **7**A and **7**B show opposite phase square wave signals generated by an oscillator of one jaw energizing circuit of the energy source; FIG. **7**C shows a relatively low duty cycle gate control signal supplied by a controller to an oscillator of one jaw energizing circuit of the energy source; FIG. **7**D shows an input power signal to a transformer of the jaw energizing circuit, formed in response to the gate control signal shown in FIG. **7**C; FIG. **7**E shows a heater power signal created by the transformer of the jaw energizing circuit in response to the input power signal shown in FIG. **7**D; FIG. **7**F shows a relatively high duty cycle gate control signal supplied by the controller to an oscillator of one jaw energizing circuit of the energy source; FIG. **7**G shows an input power signal to a transformer of the jaw energizing circuit, formed in response to the gate control signal shown in FIG. **7**F; and FIG. **7**H shows a heater power signal created by the transformer of the jaw energizing circuit in response to the input power signal shown in FIG. **7**G.

FIGS. **8**A-**8**C are graphs of signals exemplary of those present in the energy source and handpiece shown in FIG. **6**, all of which share a common time axis. Specifically, FIG. **8**A shows a waveform illustrative of either a voltage or current sense signal applied to a peak detector; FIG. **8**B shows a reset signal supplied to the peak detector; and FIG. **8**C shows a peak signal representative of the peak value which is detected and held by the peak detector in response to the sense signal shown in FIG. **8**A, with the sense signal also shown in phantom in FIG. **8**C.

FIG. **9** is a graph showing an exemplary characteristic relationship of temperature versus resistance of a jaw heating element of the handpiece shown in FIGS. **5** and **6**.

FIG. **10** is a flow chart of a process of conducting a functional verification test of the jaw heating elements and of other functionality of the thermal tissue operating system shown in FIGS. **1**-**9**.

DETAILED DESCRIPTION

A thermal tissue operating system **10** in which the present invention is incorporated is shown in FIG. **1**. The system **10** includes a handpiece **12** which is manipulated by a surgeon to grasp and compress tissue (exemplified by a vessel **13**) between jaws **14** and **16** of the handpiece **12**, and to simultaneously apply thermal heat energy from the jaws **14** and **16** to the compressed tissue in a thermal tissue operation. The thermal tissue operation may seal multiple pieces of the tissue together, cut a single piece of tissue into separate parts, or sequentially seal and then cut tissue.

The jaws **14** and **16** are brought together to compress the tissue by squeezing a lever **18** toward an adjacent handgrip **20** of the handpiece **12**. Internal mechanical components of the handpiece **12** (not shown but described in the above-application Ser. No. 12/842,399 convert the pivoting movement of the lever **18** relative to the handgrip **20** into motion which is transferred through a shaft **22** to a jaw movement mechanism **24** (which is described in detail in the above application Ser. No. 12/842,327. The jaw movement mechanism **24** converts the longitudinal movement from the shaft **22** into movement to move the jaws **14** and **16** toward and away from one another. Movement of the jaws **14** and **16** toward one another grips and compresses the tissue between the jaws. Movement of the jaws **14** and **16** away from one another opens the jaws sufficiently to accept tissue between them before gripping and compressing the tissue and releases any tissue previously gripped.

The thermal tissue operating system **10** also includes an electrical energy source **26** which is connected by a cable **28** to the handpiece **12**. The energy source **26** includes electrical components (FIGS. **5** and **6**) housed within an enclosure **27**. The energy source **26** supplies electrical power through the cable **28** to a pair of heat-producing resistive elements (**30** and **32**, FIGS. **5** and **6**) that are embedded within or associated with the jaws **14** and **16** (FIG. **1**). Electrical power conducted through the jaw heating elements (**30** and **32**, FIGS. **5** and **6**) is converted into heat energy and is applied to the tissue gripped and compressed between the jaws **14** and **16** during the thermal tissue operation.

Electrical power is supplied when the lever **18** is pulled into proximity with the handgrip **20** and one of the switches **59** or **60** is pressed, thereby delivering a user activation signal from the handpiece **12** to the energy source **26**. In response to the user activation signal, the energy source **26** delivers electrical power to the jaw heating elements (**30** and **32**, FIGS. **5** and **6**) of the jaws **14** and **16**. Alternatively, the activation signal may be supplied by pulling the lever **18** into proximity with the handgrip **20** and pressing a foot switch **34** which is connected to the energy source **26**. The surgeon depresses the foot switch **34** with his or her foot.

To accomplish a thermal tissue operation, the energy source **26** delivers electrical power to the jaw heating elements (**30** and **32**, FIGS. **5** and **6**), and that electrical power is converted into thermal energy and applied to the tissue. The thermal energy is delivered to the tissue compressed between the jaws **14** and **16** in accordance with a temperature versus time profile (**36** or **36'**, **37**, **46**, FIG. **2**A or **2**B, **3** and **4**) which is established for each type of thermal tissue operation. The temperature is achieved and controlled by the rate of energy delivered from the energy source **26** using temperature-based feedback signals from the jaws **14** and **16** of the handpiece **12**. The energy source **26** controls the rate of electrical energy delivery to the jaw heating elements based on the measurement of the temperature at the jaws **14** and **16** for the duration of the thermal tissue operation. Desired temperature versus time profiles to accomplish the thermal tissue operations are shown in FIGS. **2**A, **2**B, **3** and **4**.

One exemplary temperature versus time profile **36** for accomplishing a tissue sealing operation is shown in FIG. **2**A. At time **38**, the energy source **26** receives the activation signal to initiate the tissue sealing operation. The energy source **26** immediately delivers relatively high or maximum power to the jaw heating elements (**30** and **32**, FIGS. **5** and **6**) to rapidly achieve a preliminary sealing temperature **39**. Thereafter, the energy source **26** delivers a relatively lower amount of power to the jaw heating elements to achieve the final sealing temperature **40** less rapidly. Reducing the rate of temperature increase from the preliminary sealing temperature **39** to the final sealing temperature **40** reduces the possibility of an overshoot in the final sealing temperature **40**. Upon reaching the final sealing temperature **40**, the energy source **26** regulates the amount of electrical power supplied to the jaw heating elements to maintain the temperature **40** over the remaining portion of a tissue sealing time interval **42**.

The length of tissue sealing time interval **42** ends when either a predetermined minimum amount of electrical energy has been transferred to the jaw heating elements and a predetermined minimum amount of time has elapsed from the activation time **38**, or a predetermined maximum amount of time for the sealing time interval **42** has elapsed. The amount of electrical energy transmitted to the tissue is the sum of the electrical energy transmitted to both jaw heating elements (**30** and **32**, FIGS. **5** and **6**) of the jaws **14** and **16** (FIG. **1**). The total amount of electrical energy delivered throughout the progression of the time interval **42** is calculated and compared to the predetermined combined minimum amount of electrical energy, and the time elapsed since the start of the tissue sealing operation at **38** is compared with the predetermined minimum and maximum times for the tissue sealing operation to determine when either of the two above-described conditions for ending the tissue sealing operation are met.

When either of the two above-described conditions for ending the tissue seal operation are met, the energy source **26** terminates the delivery of power to the jaw heating elements, allowing the jaw heating elements to cool and decrease in temperature. The preferred sealing temperature **40** is approximately 170° C., and the predetermined minimum and maximum tissue sealing times vary from approximately 2 to 5 seconds, respectively. Preferably, the sealing temperature **40**, the minimum and maximum tissue sealing times, and other information are stored within a handpiece processor **66** (FIGS. **5** and **6**) of the handpiece **12** and are downloaded to the power system **26** prior to performing a thermal tissue operation. Different values of the thermal tissue operation-related variables are stored in different handpieces having different jaw heating elements with different electrical and thermal characteristics, to perform thermal tissue operations with the different types of handpieces.

Another exemplary temperature versus time profile **36'** for accomplishing a tissue sealing operation is shown in FIG. **2**B. The temperature versus time profile **36'** is similar to that profile **36** shown in FIG. **2**A, except that the energy source **26** delivers relatively high or maximum power to the jaw heating elements (**30** and **32**, FIGS. **5** and **6**) to achieve the final sealing temperature **40** more rapidly. Upon reaching the final sealing temperature **40**, the energy source **26** regulates the amount of electrical power supplied to the jaw heating elements to maintain the temperature **40** during a final temperature maintenance time interval **43** after the final sealing temperature **40** is initially reached. The entire tissue sealing time interval **42** is therefore slightly greater in time than the final temperature maintenance interval **43**, because the entire tissue sealing time interval **42** also includes the time between the assertion of the initial user activation signal at **38** until the final sealing temperature **40** is reached at the beginning of the final temperature maintenance interval **43**.

In the tissue sealing temperature versus time profile **36'**, the final sealing temperature **40** is maintained for the duration of the maintenance time interval **43**. The tissue sealing time interval **42** ends when the final sealing temperature **40** has been maintained within slight limits of variation for the duration maintenance time interval **43**. No determination is made of whether a predetermined minimum amount of electrical energy has been transferred to the jaw heating elements when the tissue sealing profile **36'** is performed. The time elapsed since the activation time **38** is measured, and if that time exceeds a predetermined maximum amount of time, the thermal tissue sealing operation is terminated because under the assumption that some issue has arisen which will prevent the proper execution of a sealing thermal tissue operation.

In the tissue sealing thermal operation represented by the temperature versus time profile **36'**, the final temperature maintenance interval **43** is approximately 2 seconds in time duration and the final sealing temperature **40** is approximately 150° C. Timing the 2 second final temperature maintenance interval **43** begins when the temperature is within approximately 10° C. of the desired 150° C. final sealing temperature **40**. The temperature **39** exemplifies the starting point for measuring the temperature maintenance interval **43**, because the temperature **39** is approximately 10° C. less than the final desired sealing temperature. The benefit of the tissue sealing profile **36'** over the tissue sealing profile **36** (FIG. **2**A) is that, in some cases involving some tissues in some procedures, adequate tissue seals may be obtained using a lower temperature for a shorter duration of time.

The predetermined maximum time duration allowable for a thermal tissue sealing operation, the final desired 150° C. temperature, and other information are stored within a handpiece processor **66** (FIGS. **5** and **6**) of the handpiece **12** and are downloaded to the energy source **26** prior to performing a thermal tissue operation. Different values of the thermal tissue operation-related variables are stored in different handpieces having different jaw heating elements with different electrical and thermal characteristics, to perform thermal tissue operations with the different types of handpieces.

A tissue cutting operation can also be performed independently of a tissue seal operation. A tissue cutting operation is typically performed after one or more tissue sealing operations have sealed the tissue or vessel which is to be cut. An exemplary temperature versus time profile **37** for accomplishing a tissue cut operation is shown in FIG. **3**. At time **45**, an activation signal is delivered to the energy source **26**, and the tissue cutting operation starts. During the tissue cutting operation, the energy source **26** alternately supplies relatively high power to the jaw heating elements during power delivery periods **49** followed by terminating the supply of power to the jaw heating elements during power off periods **51**. The power delivery periods **49** are preferably about 100 ms in time duration and the power off periods **51** are preferably about 200 ms in duration. The power delivery periods **49** and power off periods **51** are repeated in succession until the temperature of the jaw heating elements reaches a preliminary cutting temperature **47**. Thereafter, a lower amount of power is delivered during the following power delivery periods **49**. The power delivery periods **49** and power off periods **51** are continued until the temperature of the jaw heating elements reaches a final cutting temperature **48**, at which time **52** the tissue cutting operation is complete and the supply of power to the jaw heating elements is terminated completely.

Preferred temperatures for the respective preliminary and final cutting temperatures **47** and **48** vary depending on the electrical and thermal characteristics of the jaw heating elements, but are generally between 200-240° C. and 270-280° C., respectively. A slight amount of overshoot of both the preliminary and final cutting temperatures **47** and **48** may occur during the respective power delivery periods **49** when the temperatures **47** and **48** are first reached. This slight overshoot is due to the energy source **26** completing the delivery of power during the power delivery period **49** when the temperatures **47** and **48** are first attained.

The time between the start time **45** and finish time **52** of the tissue cutting operation is the cutting time interval **50**. The cutting time interval **50** varies for different tissue cutting operations due to differences in the amount of tissue to be cut between the jaws **14** and **16** (FIG. **1**), the temperature of the jaw heating elements at the start time **45** of the cutting time interval **50**, and the electrical and thermal characteristics of the jaw heating elements, among other factors.

The amount of energy delivered during the cutting time interval **50** is sufficient to disintegrate the tissue squeezed and compressed between the jaws **14** and **16** (FIG. **1**). The disintegration permits the tissue to be separated into parts, without destroying, disintegrating or otherwise adversely compromising the quality of a seal which may be closely located on opposite sides of a generally linear delineation where the tissue cutting or disintegration occurs.

The successive power delivery periods **49** and power off periods **51** cause the temperature versus time profile **37** for the tissue cutting operation to resemble an inclined saw tooth shape. The inclined saw tooth shaped tissue cutting profile has been discovered to possess superior tissue cutting characteristics versus a conventional ramp profile when the temperature is continually increased until a desired final cutting temperature is reached.

The temperature versus time profiles **36** (FIG. **2**A) and **37** (FIG. **3**) can be combined to form a temperature versus time profile **46**, shown in FIG. **4**, for a combined tissue sealing and cutting operation. The temperature versus time profiles **36'** (FIG. **2**B) and **37** (FIG. **3**) can also be combined to form a temperature versus time profile (not specifically shown but similar to the profile **46** shown in FIG. **4**) for a combined tissue sealing and cutting operation. The combined tissue sealing and cutting temperature versus time profile **46** resembles the temperature versus time profile **36** (FIG. **2**A) or **36'** (FIG. **2**B) from a starting time **38** to an intermediate time **44** when the tissue sealing profile portion (**36** or **36'**, FIG. **2**A or **2**B) of the operation is complete. The tissue is then allowed to cool slightly during a cooling time interval **41** between the end of the tissue sealing operation at time **44** and the start of the tissue cutting operation at time **45**. The cooling time interval **41** is approximately one second in duration, and is instrumental in contributing to a more effective and efficient tissue sealing and cutting operation, compared to performing the tissue sealing and cutting operations directly in sequence without a cooling time interval **41**.

Between times **45** and **52**, the temperature versus time profile **46** resembles the temperature versus time profile **37** (FIG. **3**) of the tissue cutting operation. The energy source **26** alternately supplies relatively high power to the jaw heating elements during power delivery periods **49** followed by terminating the supply of power to the jaw heating elements during power off periods **51**. The power delivery periods **49** are preferably about 100 ms in time duration and the power off periods **51** are preferably about 200 ms in duration. The power delivery periods **49** and power off periods **51** are repeated in succession until the temperature of the jaw heating elements reaches a preliminary cutting temperature **47**. Thereafter, a lower amount of power is delivered during the following power delivery periods **49**. The power delivery periods **49** and power off periods **51** are continued until the temperature of the jaw heating elements reaches a final cutting temperature **48**, at which time **52** the tissue cutting operation is complete and the supply of power to the jaw heating elements is terminated completely.

Preferred temperatures for the respective preliminary and final cutting temperatures **47** and **48** vary depending on the electrical and thermal characteristics of the jaw heating elements, but are generally between 200-240° C. and 270-280° C., respectively. A slight amount of overshoot of both the preliminary and final cutting temperatures **47** and **48** may occur during the respective power delivery periods **49** when the temperatures **47** and **48** are first reached. This slight overshoot is due to the energy source **26** completing the delivery of power during the power delivery period **49** when the temperatures **47** and **48** are first attained.

The time between the start time **45** and the finish time **52** of the tissue cutting operation is the cutting time interval **50**. The cutting time interval **50** varies for different tissue cutting operations due to differences in the amount of tissue to be cut between the jaws **14** and **16** (FIG. **1**), the temperature of the jaw heating elements at the start time **45** of the cutting time interval **50**, and the electrical and thermal characteristics of the jaw heating elements, among other factors.

As shown in FIG. **1**, a display **54** and a speaker **56** are included within the enclosure **27** of the energy source **26**. The display **54** and the speaker **56** convey information about the functional response characteristics of the thermal tissue operating system **10**, during use of the system. The energy source **26** also includes mode selection controls or switches **58**. The handpiece **12** includes selection thumb switches **59** on opposite sides of the handgrip **20** (only one selection switch **59** is shown in FIG. **1**). The handpiece **12** also includes a finger selection switch **60** on the lever **18**. The mode control switches **58** are used to select between a manual mode of operation and an automatic mode of operation. In the manual mode of operation, a tissue cut operation is activated by pulling the lever **18** back toward the handgrip **20** and then depressing one of the thumb switches **59**. In the manual mode of operation, a tissue seal operation is activated by depressing the finger switch **60** when the lever **18** is pulled back toward the handgrip **20**. In the automatic mode of operation, a combined tissue sealing and cutting operation is activated by depressing the switch **60** when the lever **18** is pulled back toward the handgrip **20**. In the automatic mode of operation, pressing the switch **59** with the lever **18** pulled back toward the handgrip **20** activates a manual cut operation.

The present invention relates to performing a functional verification test at test intervals which occur between sequential thermal tissue operations during the course of the surgical procedure. The functional verification test is principally useful to determine whether potentially-degrading changes have occurred in the resistance characteristics of the jaw heating elements **30** and **32** of the handpiece **12**. The functional verification test is also useful to determine other aspects of proper operation of the energy source **26**. The details of the functional verification test are described below in connection with FIG. **10**. The details of the functional verification test are understood by reference to FIGS. **5-9**.

As shown in FIG. **5**, the energy source **26** includes a control processor **62** and a monitor processor **64**. The control processor **62** generally controls the operation and overall functionality of the energy source **26**, as well as performing and participating in the performance of the self-tests described herein. The monitor processor **64** monitors the operation of the control processor **62** and otherwise performs many of its own functional tests to ensure that the control processor **62** and other sub-components are operating as expected.

A handpiece processor **66** of the handpiece **12** controls the operation of the handpiece **12**, in response to signals from the lever **18** and switches **59** and **60** (FIG. **1**) and signals from the control processor **62** communicated over a communication bus **68** which is part of the cable **28** (FIG. **1**) connecting the energy source **26** with the handpiece **12**. The monitor processor **64** is also connected to the communication bus **68** to enable it to communicate with the handpiece processor **66** and the control processor **62**. In addition, the control processor **62** and the monitor processor **64** are directly connected together by a separate bus **70**, for direct communication of signals between those processors **62** and **64**.

Either individually or by cooperative combination of functionalities with one or more of the other processors, one or more of the processors **62**, **64** and **66** constitute a controller for the energy source **26**, a controller for the handpiece **12**, and a controller for the thermal tissue operating system **10**. Even though the components **62**, **64** and **66** are described in their exemplary form as processors, any type of computational device, data processing device, controller or programmable logic gate device, which is capable of performing the functions described herein as attributable to the components **62**, **64** and **66**, may constitute processors **62**, **64** and **66**.

Communication between the processors **62**, **64** and **66** is accomplished by using a predefined communication protocol, which is implemented within a communication routine **72** of the control processor **62**, the monitor processor **64** and the handpiece processor **66**. Executing the communication routine **72** allows the transfer of information between the processors **62**, **64** and **66** over the bus **68**. The processors **62**, **64** and **66** include memory modules **73**, **74** and **75**, which store the programs that the processors **62**, **64** and **66** execute to achieve their respective functionalities. In addition, user input and output (I/O) **67** is communicated to the control processor **62** by use of the display **54**, the speaker **56** and the front panel controls **58** of the energy source (FIG. **1**). User input **69** is also communicated to the handpiece processor **66** by movement of the lever **18** and the depression of the thumb switches **59** and finger switch **60** (FIG. **1**).

The energy source **26** also includes a first jaw energizing circuit **76** which supplies a heater power signal **77** to the heating element **30** in the jaw **14** of the handpiece **12**. The energy source **26** also includes a second jaw energizing circuit **78** which supplies a heater power signal **79** to the heating element **32** in the jaw **16** of the handpiece **12**. The heater power signals **77** and **79** establish the amount of electrical power delivered to the jaw heating elements **30** and **32**. The heater power signals **77** and **79** are converted into thermal energy by the jaw heating elements **30** and **32** to accomplish the thermal tissue operations. The heater power signals **77** and **79** are conducted from the energy source **26** to the handpiece **12** through conductors in the cable **28**.

The jaw energizing circuits **76** and **78** are independently and respectively controlled by the control processor **62** asserting gate control signals **134** and **136**. The gate control signals **134** and **136** control characteristics of the separate heater power signals **77** and **79** delivered to each jaw heating element **30** and **32**, thereby allowing the temperature of each jaw heating element **30** and **32** to be individually controlled in response to individual temperature feedback controls from each jaw heating element. Independent regulation of the temperature of each heating element **30** and **32** allows the temperature of the tissue gripped between the jaws **14** and **16** to be more precisely controlled to achieve the desired temperature characteristics for a seal operation, a cut operation and a combined seal and cut operation. The monitor processor **64** enables the jaw energizing circuits **76** and **78** to deliver the heater power signals **77** and **79** by asserting enable signals **154** and **156**, respectively. Whenever an enable signal **154** or **156** is de-asserted, the respective jaw energizing circuit **76** or **78** will not create the heater power signal **77** or **79**.

Simulation circuits **80** and **81** are connected to the jaw energizing circuits **76** and **78** to receive the heater power signals **77** and **79**, respectively, under the control of the monitor processor **64**, when it is desired to conduct certain functional integrity tests described below. When deactivated by the monitor processor **64** de-asserting activation signals **146** and **148**, the simulation circuits **80** and **81** conduct the heater power signals **77** and **79** through internal load simulating heating elements (**150** and **152**, FIG. **6**) within the simulation circuits **80** and **81**, respectively. When activated by the monitor processor **64** asserting the activation signals **146** and **148**, the simulation circuits **80** and **81** conduct the heater power signals **77** and **79** to the heating elements **30** and **32** of the jaws **14** and **16**, respectively. Conducting the functional integrity tests of the energy source **26** with the simulation circuits **80** and **81** ensures that the thermal tissue operating system is working properly.

The handpiece **12** includes a voltage measurement circuit **82** that detects the voltage across the heating elements **30** and **32** of the jaws **14** and **16** when the heater power signals **77** and **79** cause current flow through those heating elements **30** and **32**. The handpiece processor **66** communicates the voltage values from the measurement circuit **82** over the bus **68** to the control and monitor processors **62** and **64**. The control processor **62** uses those voltage values to calculate power and energy delivered to and consumed by the heating elements **30** and **32**. Measuring the voltage across the heating elements **30** and **32** at the jaws provides greater accuracy in the measurement of the power and energy consumed by the jaw heating elements **30** and **32**, because losses resulting from conducting the power heating signals **77** and **79** through the conductors of the cable **28** are not involved in the voltage values detected by the measurement circuit **82**. Independent determinations of the power and energy delivered to and consumed by each of the heating elements **30** and **32** facilitate individual control over each of the heating elements **30** and **32**.

More details concerning the jaw energizing circuits and **76** and **78**, the simulation circuits **80** and **81** and the functionality of the control and monitor processors **62** and **64** of the energy source **26**, as well as the heating elements **30** and **32**, the measurement circuit **82** and the handpiece processor **66** of the handpiece **12**, are shown and discussed in connection with FIG. **6**.

The jaw energizing circuits **76** and **78** are each substantially identical in construction and functionality, although each jaw energizing circuit **76** and **78** is separately controllable. Each jaw energizing circuit **76** and **78** respectively includes a variable voltage power supply **84** and **86**. Each variable voltage power supply **84** and **86** is connected to a conventional commercial energy source (not shown). Each power supply **84** and **86** converts commercial power to direct current power at a voltage established by each power supply **84** and **86** in response to voltage control signals **88** and **90** supplied by the control processor **62** to each power supply **84** and **86**, respectively. Each jaw energizing circuit **76** and **78** is therefore capable of supplying the heater power signal **77** and **79**, respectively, at different and individually controlled voltage levels established by the control signals **88** and **90**.

Voltage sensors **92** and **94** are connected to sense the output voltage from the variable voltage power supplies **84** and **86**. The voltage sensors **92** and **94** supply voltage sense signals **96** and **98** to the monitor processor **64** in response to the voltages of the electrical energy delivered from the variable voltage power supplies **84** and **86**. The ability to individually adjust the voltage from each power supply **84** and **86** allows adjustment to compensate for slight variations in the resistances of each jaw heating element **30** and **32**. Changing the voltage to compensate for a slightly changed resistance of a jaw heating element **30** or **32** causes each jaw heating element to consume approximately the same amount of electrical energy and thereby generate approximately the same amount of thermal energy, for similar gate control signals applied, as discussed below.

Electrical energy at the output voltage of the power supplies **84** and **86** is supplied to center taps **100** and **102** of a center tapped primary winding of power output transformers **104** and **106**, respectively. The primary windings of the power output transformers **104** and **106** are therefore divided into two winding segments **108**, **110** and **112**, **114** by the center taps **100** and **102**, respectively. The upper (as shown) winding segments **108** and **112** are connected to switches **116** and **120**, respectively. The lower (as shown) winding segments **110** and **114** are connected to switches **118** and **122**, respectively. When the switches **116** and **120** are conductive, current is conducted through the winding segments **108** and **112** from the variable voltage power supplies **84** and **86** through current sensors **95** and **97**, respectively, to reference potential **99**. When the switches **118** and **122** are conductive, current is conducted through the winding segments **110** and **114** from the variable voltage power supplies **84** and **86**, through the current sensors **95** and **97**, respectively, to the reference potential **99**.

Each of the jaw energizing circuits **76** and **78** includes its own oscillator **128** and **129**, respectively. The switches **116** and **118** conduct in response to signals generated by the oscillator **128**, and the switches **120** and **122** conduct in response to signals generated by the oscillator **129**. The oscillators **128** and **129** each generate two substantially similar or identical relatively high frequency, e.g. 50 kHz, square wave signals **130** and **132** (FIGS. **7**A and **7**B). The square wave signals **130** and **132** are phase shifted with respect to one another by 180 degrees. The square wave signal **130** is applied to the switches **116** and **120**. The square wave signal **132** is applied to the switches **118** and **122**. The switches **116-122** are capable of conducting current from the primary winding segments **108-114** of the of the power output transformers **104** and **106**, only when the square wave signals **130** and **132** are a positive value. During the times that the square wave signals **130** and **132** are at reference or zero value, the switches **116-122** are not capable of conducting.

A gate control signal **134** is applied from the control processor **62** to the oscillator **128**, and a gate control signal **136** is applied from the control processor **62** to the oscillator **129**. Upon assertion of the gate control signal **134**, the oscillator **128** conducts the square wave signals **130** and **132**, respectively, for the duration of the assertion of the gate control signal **134**. Because the square wave signals **130** and **132** are phase shifted with respect to one another by 180 degrees, the alternating conductivity of the switches **116** and **118** conducts current in opposite directions through the primary windings **108** and **110** from the center tap **100**, thereby establishing a primary alternating current signal **138** (FIG. **7**D) which is conducted through the primary winding segments **108** and **110** of the power output transformer **104**. Similarly, upon assertion of the gate control signal **136**, the oscillator **129** conducts the square wave signals **130** and **132**, respectively, for the duration of the assertion of the gate control signal **136**. Because the square wave signals **130** and **132** are phase shifted with respect to one another by 180 degrees, the alternating conductivity of the switches **120** and **122** conducts current in opposite directions through the primary windings **112** and **114** from the center tap **102**, thereby establishing a primary alternating current signal **140** (FIG. **7**G) which is conducted through the primary winding segments **112** and **114** of the power output transformer **106**. The primary alternating current signals **138** and **140** induce the heater power signals **77** and **79** from the secondary windings **124** and **126** of the power output transformers **104** and **106**, respectively.

The amount of electrical energy contained in the heater power signals **77** and **79** is directly related to the voltage from the variable voltage power supplies **84** and **86**, respectively, and is also directly related to the time duration of the gate control signals **134** and **136**. Asserting the gate control signals **134** and **136** for a longer time duration results in the switches **116**, **118** and **120**, **122** conducting the primary alternating current signals **138** and **140** through the primary winding segments **108**, **110** and **112**, **114** of the power output transformers **104** and **106** for a greater duration of time, thereby causing greater energy content in the heater power signals **77** and **79**, respectively. Conversely, asserting the gate control signals **134** and **136** for a shorter time duration results in the switches **116**, **118** and **120**, **122** conducting the primary alternating current signals **138** and **140** through the primary winding segments **108**, **110** and **112**, **114** of the power output transformers **104** and **106** for lesser duration of time, thereby causing lesser energy in the heater power control signals **77** and **79**.

The control processor **62** independently controls the duration of the gate control signals **134** and **136**, thereby controlling the amount of electrical energy delivered to the jaw heating elements **30** and **32** for conversion into thermal energy to establish and maintain the desired temperature of the jaw heating elements. The thermal loads experienced by each of the jaws **14** and **16** are somewhat different. It is because of the different thermal loads that the control processor **62** exercises independent control over each of the jaw energizing circuits **76** and **78** by separately establishing the time duration of each of the gate control signals **134** and **136**, which in turn separately establish the electrical energy content of the heater power signals **77** and **79**. FIGS. **7**C and **7**F illustrate the separate and individual control of each gate control signal **134** and **136**.

The power and consequently temperature control of the jaw heating elements **30** and **32** is performed by the control processor **62** on a control cycle basis. A control routine **103** is executed by the control processor **62** in accordance with the selected thermal tissue operation, and the temperature versus time profile **36** or **36'**, **37** and **46** (FIG. **2**A or **2**B, **3** and **4**, respectively) of the selected thermal tissue operation, in response to the user activation signal. The control routine **103** invokes a conventional feedback pulse width modulation routine **101** that establishes the time duration of the gate control signals **134** and **136** for each control cycle **104** in relation to the temperature of the jaw heating elements **30** and **32**. The control processor **62** supplies the gate control signals **134** and **136** to the oscillators **128** and **129**, and the duration of the gate control signals **134** and **136** establish the desired number of pulses of the square wave signals **130** and **132** conducted during each control cycle to create heater power signals **77** and **79**.

The duty cycle of the gate control signals **134** and **136** during each control cycle **104** controls the amount of electrical energy delivered to the jaw heating elements during that control cycle, as understood by reference to FIGS. **7**A-**7**H. The exemplary signals shown in FIGS. **7**A-**7**H extend over two control cycles **104**. The square wave signals **130** and **132** produced by the oscillators **128** and **129** are shown in FIGS. **7**A and **7**B. A relatively low duty cycle gate control signal **134** supplied by the control processor **62** is shown in FIG. **7**C. The relatively low duty cycle gate control signal **134** shown in FIG. **7**C has an on time that extends from t_0 to t_1 and an off time that extends from t_1 to t_3 in the first shown control cycle **104** and an on time that extends from t_3 to t_4 and an off time that extends from t_4 to t_6 in the second control cycle **104**. The relatively low duty cycle of the gate control signal **134** creates the primary alternating current signal **138** shown in FIG. **7**D that is formed by two cycles of square wave signals **130** and **132**.

A relatively high duty cycle gate control signal **136** supplied by the control processor **62** is shown in FIG. **7**F. The relatively high duty cycle gate control signal **136** shown in FIG. **7**F has a much longer on time and a much shorter off time compared to the on and off times of the gate control signal **134** shown in FIG. **7**C. The on time of the relatively high duty cycle gate control signal **136** shown in FIG. **7**F extends from t_0 to t_2 and its off time extends from t_2 to t_3 in the first control cycle **104**. Similarly in the second control cycle **104** shown in FIG. **7**F, the longer on time extends from t_3 to t_5 and the shorter off time extends from t_5 to t_6. The relatively high duty cycle of the gate control signal **136** creates the primary alternating current signal **140** shown in FIG. **7**G that is formed by four cycles of square wave signals **130** and **132**.

Thus, the control processor **62** varies the amount of energy of the heater power signals **77** and **79** by varying the duty cycle of the gate control signals **134** and **136**. Varying the duty cycle of the gate control signals **134** causes the oscillators **128** and **129** to vary the number of pulses of the square wave signals **130** and **132** conducted to the switches **116**-**122**, which in turn varies the time duration that the primary alternating current signals **138** and **140** are present during each control cycle **104**. Fewer and greater numbers of pulses of the square wave signals **130** and **132** during each control cycle **104** result in less and more electrical energy reaching the jaw heating elements **30** and **32** during each control cycle **104**, respectively. The exemplary control cycles shown in FIGS. **7**A-**7**H have six pulses of square wave signals **130** and **132** forming each control cycle **104**, for illustrative purposes only; in actuality, each control cycle **104** will typically have a considerably greater number of pulses of the square wave signals **130** and **132**. In a practical embodiment of the thermal tissue operating system, the length of a control cycle **104** is about 5 ms.

The primary alternating current signals **138** and **140** are conducted through the primary winding segments **108**, **110** and **112**, **114** of output transformers **104** and **106**, as shown in FIG. **6**. In response, the transformers **104** and **106** respectively induce heater power signals **77** and **79** from their secondary windings **124** and **126**. Other than slight reductions caused by the losses which occur in the transformers **104** and **106**, the energy content of the heater power signals **77** and **79** is approximately the same as the energy content of the primary alternating current signals **138** and **140**.

The heater power signals **77** and **79** are conducted to relays **142** and **144** of the simulation circuits **80** and **81**, respectively. The relays **142** and **144** are activated and deactivated by the assertion and deassertion of relay activation signals **146** and **148** supplied by the monitor processor **64**. When the relays **142** and **144** are deactivated, the heater power signal **77** and **79** pass through the relays **142** and **144** to load-simulation heating elements **150** and **152**. The load-simulation heating elements **150** and **152** are a part of the energy source **26** and are located within the enclosure **27** (FIG. **1**) of the energy source **26**. When the relays **142** and **144** are activated, the heater power signals **77** and **79** are conducted through the cable **28** to the jaw heating elements **30** and **32** of the handpiece **12**.

For the heater power signals **77** and **79** to reach the jaw heating elements **30** and **32** of the handpiece **12**, the monitor processor **64** must be fully functional and must determine that the operation of the energy source **26** and handpiece **12** is appropriate and within safe limits. It is under these circumstances that the relay activation signals **146** and **148** are asserted by the monitor processor **64**, to activate the relays **142** and **144** and thereby permit the heater power signals **77** and **79** to reach the jaw heating elements **30** and **32**, respectively. The relays **142** and **144** are examples of controllable switches that receive control signals, such as the relay activation signals **146** and **148**, to change between conductive states.

In addition to deactivating the relays **142** and **144** to terminate the supply of power to the jaw heating elements **30** and **32**, the monitor processor **64** can separately terminate the creation of the heater power signals **77** and **79** in the jaw energizing circuits **76** and **78**, by deasserting enable signals **154** and **156** applied to the oscillators **128** and **129**, respectively. The oscillators **128** and **129** generate the square wave signals **130** and **132** only when the enable signals **154** and **156** are asserted by the monitor processor **64**. When the enable signals **154** and **156** are de-asserted, the oscillators **128** and **129** do not generate the square wave signals **130** and **132**, and the heater power signals **77** and **79** are not created.

When the switches **116**, **118** and **120**, **122** are conductive, the current flowing through those switches passes through current sensors **95** and **97**. The current sensors **95** and **97** measure the amount of current flowing through the primary winding segments **108**, **110** and **112**,**114** of the power output transformers **104** and **106**, respectively. The sensors **95** and **97** supply primary winding current sense signals **162** and **164** having magnitudes which represent the magnitudes of the current flowing in the primary windings of the transformers **104** and **106**, respectively. The voltage sensors **92** and **94** supply the voltage sense signals **96** and **98** which have magnitudes that represent the respective magnitudes of the voltage applied across the primary winding segments **108**, **110** and **112**, **114** of the transformers **104** and **106**, respectively.

Current sensors **166** and **168** are connected to the secondary windings **124** and **126** of the power output transformers **104** and **106** to measure the current of the heater power signals **77** and **79**, respectively. The current sensors **166** and **168** supply secondary or output current sense signals **170** and **172** having magnitudes which represent the magnitudes of the current of the heater power signals **77** and **79**.

The primary current sense signals **162** and **164** are applied to peak current detectors **174** and **176**, respectively, and the secondary current sense signals **170** and **172** are applied to peak current detectors **178** and **180**, respectively. The peak current detectors **174**-**180** are each conventional and include conventional peak hold circuitry to detect and hold the highest or peak magnitude of any signal applied to the peak hold circuits, until the peak current detectors are reset. The peak current detectors **174**, **176**, **178** and **180** hold the peak magnitudes of the current signals **162**, **164**, **170** and **172**, respectively, as peak magnitude current signals **162'**, **164'**, **170'** and **172'**, until reset. The peak magnitude current signals **162'**, **164'**, **170'** and **172'** therefore represent the peak magnitudes of the current sense signals **162**, **164**, **170** and **172** during a sampling period of the detectors **174**-**180**, respectively.

The sampling periods of the peak current detectors **174**-**180** are established by reset signals **182** and **184** which are asserted by the monitor and control processors **64** and **62** respectively. The reset signal **182** is asserted to the peak current detectors **174** and **176**, and the reset signal **184** is asserted to the peak current detectors **178** and **180**. The reset signals **182** and **184** (comparable to the reset signals **198**_a_ and **198**_b_, FIG. **8**B) are asserted once during each control cycle period **104** (FIGS. **7**A-**7**H), to assure that the peak current values **162'**, **164'**, **170'** and **172'** of the current conducted during that control cycle are obtained for use by the control and monitor processors **62** and **64** in regulating the output power and in controlling and monitoring the functionality of the energy source **26**.

The peak magnitude current signals **170'** and **172'** are supplied to an analog to digital converter (ADC) **186**. As shown in FIG. **6**, the ADC **186** is an internal component of the control processor **62**; however, the ADC **186** could also be a separate external component of the control processor **62**. The ADC **186** converts the analog values of the peak current signals **170'** and **172'** to corresponding digital values at sampling points within each control cycle period **104**. The sampling points are determined by a sequencer **188**, which generally controls the sequence of all functions performed by the control processor **62**, including supplying the converted peak digital values **170'** and **172'** of the corresponding analog peak current signals **170** and **172** to other routines executed by the control processor **62**. The monitor processor **64** and the handpiece processor **66** also have ADCs and sequencers (neither shown) which operate in a similar manner to the ADC **186** and the sequencer **188** of the control processor **62**.

Voltage sense signals **190** and **192** represent the voltages across the jaw heating elements **30** and **32**, respectively. The voltage sense signals **190** and **192** are supplied to peak voltage detectors **194** and **196** within the handpiece **12**. The peak voltage detectors **194** and **196** are conventional and include circuitry which detects and holds the maximum or peak value of the voltage sense signals **190** and **192** until the peak voltage detectors **194** and **196** are reset. The detectors **194** and **196** supply peak voltage signals **190'** and **192'** to the handpiece processor **66**. The peak voltage signals **190'** and **192'** correspond to the peak or maximum values of the analog voltage sense signals **190** and **192** over a sampling period of the peak voltage detectors **194** and **196**. The sampling period of the peak voltage detectors **194** and **196** is established by a reset signal **198** (**198***a*, **198***b*, FIG. **8**B) asserted by the handpiece processor **66**. The reset signal **198** is asserted once during each control cycle **104** (FIGS. **7**A-**7**H), to assure that the peak values of the voltages applied to the jaw heating elements **30** and **32** during that control cycle are obtained for use in controlling and monitoring the functionality of the energy source **26**.

The peak detectors **174**, **176**, **178**, **180**, **194** and **196** all operate in similar manner. The following description of peak detector functionality is presented in reference to exemplary signals shown in FIGS. **8**A-**8**C applied to the peak voltage detector **196**. The voltage sense signal **192** is shown in FIG. **8**A as having a variable magnitude over two control cycles **104***a* and **104***b*. Each voltage sense signal **192** is formed by four positive half-cycles of the heater power signal **79** and four negative half-cycles of the heater power signal **79** (FIG. **7**H). The positive and negative pulses of the heater power signal are rectified into positive values as shown in FIG. **8**A by a conventional rectifying capability of the peak detector **196**. The rectifying capability assures that the maximum value of both the positive and negative half-cycles of the heater power signal **79** are detected and held. The first cycle period **104***a* starts at time t_0 and ends at time t_3. The second cycle period **104***b* starts at time t_3 and ends at time t_6. Reset signals **198***a* and **198***b* are shown in FIG. **8**B as asserted prior to times t_3 and t_6, prior to the start of both control cycles **104***a* and **104***b*. The assertion of the reset signals **198***a* and **198***b* cause the peak values **192'** which are being held to dissipate or discharge as shown **199**.

The peak voltage signal **192'**, shown in FIG. **8**C, begins at a value which relates to the magnitude of the voltage sense signal **192** immediately after the reset signal has been de-asserted to the peak voltage detector **196**. Sampling the peak voltage signal **192'** begins at the start of the control cycle **104***a* and the maximum sampled magnitude for the duration of the first cycle period **104***a* is held until the reset signal **198***a* is asserted. The magnitude of the voltage sense signal **192** was near its maximum at the beginning of the control cycle **104***a*, as shown in FIG. **8**C. When the reset signal **198***a* is de-asserted at time t_3 at the beginning of the second control cycle **104***b*, the magnitude of the voltage sense signal **192** has decreased compared to the magnitude of the voltage sense signal **192** shortly after time t_0. Consequently, the initial value of the peak voltage signal **192'** at the beginning of the control cycle **104***b* starts low, but the magnitude of the peak voltage sense signal **192'** continues to increase during the control cycle **104***b*, until heater power signal **79** (FIG. **7**H) is no longer delivered when the gate control signal **136** is no longer asserted (FIGS. **6** and **7**F). Thus, the continually increasing value of the peak voltage signal **192'** during the cycle period **104***b* illustrates that each peak detector will increase the magnitude of its peak output signal whenever its input signal increases above a previous value, until reset.

The control processor **62** uses the peak voltage values **190'** and **192'** along with the peak current values **170'** and **172'** to individually calculate resistance values of the jaw heating elements **30** and **32** during each control cycle period **104**. The control processor **62** obtains the peak current values **170'** and **172'** by sampling the peak current detectors **178** and **180** during each control cycle period **104**. The control processor **62** obtains the voltage values across the heating elements **30** and **32** by issuing commands to the handpiece processor **66** requesting the peak voltage values **190'** and **192'** derived by the peak voltage detectors **194** and **196**.

The control processor **62** calculates the resistance of each of the jaw heating elements **30** and **32** during each control cycle **104** by dividing the peak voltage values **190'** and **192'** for each jaw heating element **30** and **32** by the peak current values **170'** and **172'**, respectively. The calculated resistance value is thereafter used to determine the temperature of each jaw heating element. The correlation between resistance value and temperature of each jaw heating element is obtained from the known temperature coefficient characteristic relationship between temperature and resistance of the material which forms each jaw heating element **30** and **32**. Graph **200**, shown in FIG. **9**, illustrates an exemplary positive temperature coefficient and resistance relationship. The graph **200** illustrates that for each resistance of each jaw heating element, that heating element is experiencing a single temperature. By knowing the resistance, obtained from dividing the peak voltage value by the peak current value, the corresponding temperature of the jaw heating element is obtained.

The graph **200** can be defined by an equation or by a lookup table. In either case, the equation or lookup table is stored in the memory **75** of the handpiece **12** (FIG. **5**). A separate equation or lookup tables stored in the handpiece memory **75** allows the data to be calibrated to the exact characteristic relationship of temperature and resistance of each jaw heating element **30** and **32** specifically used in each handpiece **12**. The equation or the data from the lookup table in the memory **75** of the handpiece is sent to the control processor **62** over the communication bus **68** by the handpiece processor **66** when the handpiece **12** is initially connected to the energy source **26**. In this manner, the temperature determinations are specific to the individual resistance characteristics of each jaw heating element **30** and **32**.

The ability to control the level of voltage from each variable voltage power supply **84** and **86** allows that voltage to be increased or decreased to compensate for manufacturing variances and slight variations in resistance of the jaw heating elements **30** and **32**. In the event that one of the jaw heating elements **30** or **32** has a higher or lower resistance value than expected, the voltage from the power supply **80** is increased or decreased to ensure the same power is simultaneously delivered to each jaw heating element **30** and **32**. Prior to performing a thermal tissue operation, and periodically during the procedure, the control processor **62** calculates resistance values for the jaw heating elements **30** and **32** and then signals the variable voltage power supplies **84** and **86** to adjust the voltage supplied, so that an equivalent and desired amount of power is delivered to each jaw heating element.

The level of voltage supplied from the variable voltage power supplies **84** and **86** to each jaw heating element **30** and **32** is calculated as the square root of the product of the desired power consumption of the jaw heating element at a particular time in one of the temperature versus time profiles **36** or **36'** (FIG. **2**A or **2**B), **37** (FIG. **3**) or **46** (FIG. **4**) and the calculated resistance value of that jaw heater. Varying the voltage supplied to the jaw heating elements **30** and **32** in this manner ensures that equivalent amounts of electrical power are supplied to each of the jaw heating elements **30** and **32** despite the jaw heating elements **30** and **32** having different resistance values.

Varying the voltages of the variable voltage power supplies **84** and **86** is not used to regulate the temperature of the jaw heating elements **30** and **32** as part of the temperature feedback control. Instead, the temperatures of the jaw heating elements **30** and **32** are independently regulated by varying the average amount of current supplied to each of the jaw heating elements **30** and **32**. The temperature of each of the jaw heating elements **30** and **32** is separately determined from the separately calculated resistance values, as explained above. These calculated temperatures are used in a feedback control algorithm by the control processor **62** to allow individual control over each of the heater power signal **77** and **79** to individually establish, maintain and regulate the temperature of each jaw heating element **30** and **32**. Using resistance to temperature data (FIG. **9**) that is particular to each jaw heating element **30** and **32** ensures that the derived temperature is accurate, thereby allowing closer regulation of the temperature during the thermal tissue operations.

Positioning the peak voltage detectors **194** and **196** within the handpiece **12** (FIG. **6**) close the jaw heating elements **30** and **32** ensures that the voltage sense signals **190** and **192** and the corresponding peak voltage signals **190'** and **192'** are accurate by avoiding measurements that are degraded by the inherent voltage drop resulting from conducting the current of heater power signals **77** and **79** through the conductors of the cable **28** to the jaw heating elements **30** and **32** of the handpiece **12**. Current flowing in a closed circuit path is the same at any point along the path, so the position of the current sensors **166** and **168** at the secondary windings **124** and **126** of the transformers **104** and **106** respectively, accurately represents the amount of current supplied to the jaw heating elements **30** and **32**.

Some slight amount of power is inherently consumed by the transformers **104** and **106**, so the amount of power delivered to the jaw heating elements **30** and **32** calculated by the control processor **62** in multiplying the peak values **170'** and **172'** of the secondary current sense signals **170** and **172** by the peak voltage signals **190'** and **192'** is slightly different from the value of the power calculated by the monitor processor **64** in multiplying the peak values **162'** and **164'** of the primary current sense signals **162** and **164** by the value of the primary voltage sense signals **96** and **98**. Nonetheless, the comparative relationship of the power value calculated by the control processor **62** and the power value calculated by the monitor processor **64** allow the monitor processor **64** to determine whether the control processor **62** is performing appropriately under the circumstances.

The total amount of electrical energy supplied to each jaw heating element since the start of a thermal tissue operation to the end of that thermal tissue operation is calculated by adding the sum of electrical powers calculated multiplied by the time the power is delivered during each control cycle which has occurred since activation of the energy source **26** to accomplish that thermal tissue operation.

Reliable and intended operation of the thermal tissue operating system **10** is confirmed by executing a functional verification test during test intervals between thermal tissue operations, during the course of the entire surgical procedure. The functional verification test is primarily useful for determining the integrity and proper functionality of the jaw heating elements **30** and **32**, but may also be useful in determining aspects of proper functionality of the energy source **26** and/or the handpiece **12**. The control processor **62** executes the functional verification test and determines whether or not the functional verification test is successful. The monitor processor **64** oversees the timing of each functional verification test performed by the control processor **62**. The functional verification test is considered to have failed if the control processor **62** determines that the test has failed. Upon a determination of a failed functional verification test, the monitor processor **60** deactivates the relays **142** and **144** (FIG. **6**) to prevent the delivery of the heater power signals **77** and **79** to the jaw heating elements **30** and **32** of the handpiece **12**, and/or the control processor **62** deasserts the gate control signals **134** and **136** to the oscillators **128** and **129**, and/or the monitor processor **64** deasserts the enable signals **154** and **156** to the oscillators **128** and **129**. With the relays **142** and **144** deactivated and/or the oscillators **128** and **129** inoperative, the handpiece **12** can not be used in a surgical procedure. Error messages or other alerts are issued on the display **54** and/or through the speaker **56** (FIG. **1**). In this manner, the need to replace or service the energy source **26** or to replace the handpiece **12** is communicated to the user.

An exemplary process flow **300** of the functional verification test in accordance with the present invention is shown in FIG. **10** and described in conjunction with FIG. **6**. The process flow **300** is performed by the control processor **62** in conjunction with the handpiece processor **66**, when the tissue fusion system **10** is first started up or powered on, and additionally on a repeating basis between the end of the previous thermal tissue operation and the start of the next subsequent thermal tissue operation during the course of the entire surgical procedure. Each thermal tissue operation is initiated by the user activation signal. In almost every practical application of the thermal tissue operating system, the time between subsequent thermal tissue operations will be more than sufficient to accommodate at least one and typically multiple predetermined test intervals.

Both the control processor **62** and the handpiece processor **66** are programmed to perform their respective parts of the process flow **300** in a coordinated manner. The monitor processor **64** issues an error communication in the event that the control processor **62** performs the functional verification test too frequently and elevates the temperature of the jaw heating elements **30** and **32** beyond a desired level. The monitor processor **64** also issues an error communication in the event that the control processor **62** exceeds a maximum predetermined time to perform one functional verification test. In this manner, the monitor processor **64** oversees the control processor **62** to determine that the execution of the functional verification tests do not occur too frequently or for too long of a time beyond the desired time for a test interval.

The process flow **300** starts at **302**. At **304** a determination is made as to whether the functional verification test interval has expired. One purpose of the test interval is to provide an opportunity for the jaw is too cool after performing a thermal tissue operation. An exemplary time for the test interval is approximately 3 seconds. The test time interval can either be fixed in time duration, or it can be variable in time duration in relation to the temperature of the jaw heating elements **30** and **32**. For example, the test time interval may be relatively short (approximately 1 second) immediately following a thermal tissue operation, and the jaw heating elements **30** and **32** will still cool. Since the jaw heating elements are already at an elevated temperature immediately following the thermal energy operation, the minimal energy added by the functional verification test does not significantly slow the cooling of the jaws. As the jaw heating elements cool between the subsequent thermal tissue operations, the test time interval can be made longer in duration, since the functional verification test energy has a greater thermal impact when the jaw heating elements **30** and **32** are at a reduced temperature. The test interval should be that amount of time which allows the jaw heating elements to cool between subsequent functional verification tests, so that the jaws do not heat to a potentially injurious temperature from performing the functional verification tests themselves. Affording the jaw heating elements **30** and **32** an opportunity to cool between iterations of the functional verification test prevents the jaw heating elements **30** and **32** from reaching elevated temperatures sufficient to injure the surgeon or surgical personnel due to accidental contact with the jaws **14** and **16** (FIG. **1**).

If the determination at **304** is negative, the process flow **300** continues at **306**. A determination is made, at **306**, as to whether an activation signal has been received by the control processor **62**. If the determination at **306** is affirmative, then a thermal tissue operation (FIGS. **2**, **3** and **4**) is performed at **308** without performing the functional verification test. If the determination at **306** is negative, or after the thermal tissue operation has been performed at **308**, the process flow **300** returns to **304**. So long as the determinations at **304** and **306** are negative, the process flow **300** loops between the determinations at **304** and **306** until the functional verification test time interval has expired.

When the determination at **304** is affirmative after expiration of the functional verification test time interval, the process flow **300** continues to **310**. At **310**, the control processor **62** asserts the gate control signals **134** and **136** to the oscillators **128** and **129** while the monitor processor **64** asserts the enable signals **154** and **156** to enable the oscillators **128** and **129**. The monitor processor **64** also asserts the relay activation signals **146** and **148** to the relays **142** and **144**, causing test heater power signals **77** and **79** to be supplied to the jaw heating elements **30** and **32**. The control processor **62** supplies the gate control signals **134** and **136** at a low power test duty cycle for a predetermined number of control cycles **104** (FIGS. **7**A-**7**H, **8**A-**8**C), to create the low power test heater power signals **77** and **79** that are supplied to the jaw heating elements **30** and **32**.

The amount of power delivered for each test heater power signal is a finite amount greater than zero, and is equal to or preferably somewhat less than the minimum amount of power delivered to the jaw heating elements during a normal thermal tissue operation. The test heater power signals **77** and **79** used in the functional verification test are supplied for a relatively few number of control cycles **104** (FIGS. **7**A-**7**H, **8**A-**8**C). The relatively low power and fewer number of control cycles of the test heater power signals minimize the extent to which the jaw heating elements **30** and **32** increase in temperature, but nevertheless increase the temperature of the jaw heating elements enough for evaluation during the functional verification test.

At **312**, the control processor **62** obtains the peak values **170'** and **172'** from the peak current detectors **178** and **180** while the test heater power signals are applied at **310**. Also at **312**, the control processor **62** obtains peak values **190'** and **192'** from the peak voltage detectors **194** and **196**. The handpiece processor **66** sends the peak voltage values **190'** and **192'** to the control processor **62** over the communication bus **68**.

At **314**, the peak current detectors **178** and **180** and the peak voltage detectors **194** and **196** are reset. The control processor **62** resets the peak current detectors **178** and **180** by asserting the reset signal **184**. The control processor **62** also sends to the handpiece processor **66** a reset command, and in response, the handpiece processor **66** asserts the reset signal **198** to reset the peak voltage detectors **194** and **196**.

At **315**, a determination is made of the number of control cycles **104** (FIGS. **7**A-**7**H, **8**A-**8**C). It has been determined that a number, for example four, control cycles of applying the test heater power signals **77** and **79** to the jaw heating elements **30** and **32** allows the components of the peak detectors to obtain a more accurate ending value than the values obtained immediately upon initiation of the test time interval. The determination at **315** allows the predetermined number of control cycles **104** to occur before the final values of the peak voltage and peak current are obtained. The final values of the peak voltage and the peak current obtained from the last control cycle are retained for use in calculating the resistance before the peak detectors are reset at **314**. Until the last control cycle of applying the test heater power signals occurs, the determination at **315** will be negative, causing the test heater power signals to be applied during next control cycle of the test interval at **310**.

An affirmative determination at **315** allows the control processor **62** to calculate the resistance values for each of the jaw heating elements **30** and **32** at **316**. The resistance values are calculated from the peak voltage and current values obtained from the last control cycle of the test interval by dividing the peak voltage values **190'** and **192'** by the peak current values **170'** and **172'**.

At **318**, the control processor **62** determines whether or not each of the resistances calculated at **316** is within predefined range of expected resistances. The range of expected resistances accounts for normal variations in the resistances of jaw heating elements of many different handpieces **12** used with the energy source **26**. The range of expected resistances are recorded in the memory **73** of the control processor **62**.

A calculated resistance which is above the high value of the expected range indicates a diminishing cross-sectional size of a jaw heating element, or an open circuit condition, or an infinite or extremely high resistance. An extremely high resistance or open circuit will cause considerably less than the expected current to flow to the jaw heating elements **30** and **32**, resulting in substantially reduced thermal energy available for delivery to the tissue. A calculated resistance which is below the low value of the expected range indicates increased conductivity or a short circuit. A short circuit could result from the heat of a jaw heating element melting insulation material around the conductors supplying current to the jaw heating element. A very high conductivity (low resistance) or short circuit will cause the jaw heating elements to deliver reduced or minimal thermal energy to the tissue, and may overload the current conducting capability of certain elements in the energy source **26**. In these abnormal circumstances, the calculated resistance of a jaw heating element falls outside of the expected resistance range, and the abnormal resistance will adversely affect the amount of power delivered, the capability to regulate the temperature, and the quality or integrity of the thermal tissue operation performed.

A negative determination at **318** indicates that at least one of the calculated resistances is not within the expected range of resistances. Under such circumstances, the process flow **300** then continues to **320** where a counter is incremented. The count value which is incremented at **320** represents the number of times where at least one of the calculated resistances is not within the expected range during each test interval, as indicated by a negative determination at **318**. An error will be indicated upon at least one of the calculated resistances falling outside of the expected range on a consistent basis for a predetermined number of sequential test intervals. The counter value which is incremented at **320** represents the number of sequential test intervals where at least one of the calculated resistances was not within the expected range.

At **322**, a determination is made as to whether the count value exceeds a threshold. The threshold represents the number of sequential test time intervals that at least one of the calculated resistances was not within the expected range during sequential test intervals. The threshold represented at **322** therefore establishes the error condition. As an example, the threshold value represented at **322** may be three sequential test intervals.

A negative determination at **322** causes the process flow **300** to revert back to **304** to start the execution of another functional verification test during another time interval using the previously described process flow **300**. If the determination at **318** is affirmative, indicating that the calculated resistance value shows that both jaw heating elements have functionally acceptable resistance values, the counter value is reset to zero at **324**. One instance of the functional verification test demonstrating that both jaw heating elements have functionally acceptable resistance values eliminates the possibility of reaching the threshold number of negative determinations at **318**. Accordingly, resetting the counter value at **324** readies the counter to again increment and count the number of instances where at least one of the calculated resistances of the jaw heating elements is outside of the expected range, as determined by a negative determination at **318**. So long as the counter is reset at **324** before the threshold determined at **322** is reached, a continuous sequence of test intervals governed by the threshold at **322** must occur during which at least one calculated resistance of the jaw heating elements falling outside of the expected range.

An affirmative determination at **322** results in the control processor **322** entering an error state at **326**. The error state is communicated to the monitor processor **64** over the bus **70**. An error message is presented on the display **54** (FIG. **1**), and/or an audible error message is delivered through the speaker **56** (FIG. **1**), to indicate a problem with at least one of the jaw heating elements **30** and **32**. Either or both of the control processor **62** and monitor processor **64** prevent the use of the tissue fusion system **10** when the control processor **62** is in the error state at **326**. The process flow **300** ends at **328** after entering the error state at **326**. The error state at **326** is exited when a different handpiece **12** is connected to the energy source **26**.

If a malfunction occurs in the current sensors **166** and **168**, or in the peak current detectors **178** and **180**, or in the peak voltage detectors **194** and **196**, those problems will manifest themselves in inaccurate values of the quantities sensed and detected. Similarly a malfunction in the resistance calculation functionality executed by the control processor will also manifest itself as an inaccurate value of the calculated resistance. Under these circumstances, even if the actual resistance characteristics of the jaw heating elements **30** and **32** are acceptable, the resistance values calculated at **316** will be based on inaccurate values and are likely to cause a failed functional verification test. Under such circumstances, the process flow **300** will enter the error state **326**, and further use of the thermal tissue operating system **10** is prevented. Thus in this manner, certain aspects of the proper functionality of the handpiece **12** and the energy source **26** are continually evaluated and verified on an ongoing basis between thermal tissue operations of the surgical procedure.

Performing the functional verification test according to the process flow **300** detects problems with the thermal tissue operating system **10** that might otherwise go unnoticed until after a number of compromised thermal tissue operations have been performed. Detecting problems with the jaw heating elements, or the functionality of the handpiece **12** and the energy source **26**, by execution of the process flow **300** helps to reduce or eliminate the possibility of complications and excessive patient trauma.

These and other improvements and advantages will be more apparent after comprehending the full ramifications of the present invention. Presently preferred embodiments of the present invention and many of its improvements have been described with a degree of particularity. This description is of preferred examples of implementing the invention, and is not necessarily intended to limit the scope of the invention. The scope of the invention is defined by the following claims.

What is claimed:

1. A thermal tissue operating system for performing thermal tissue operations during a surgical procedure, the thermal tissue operating system including an energy source and a handpiece connected to the energy source, the handpiece including a first jaw and a second jaw configured to compress tissue therebetween during the thermal tissue operation, the first jaw including a first jaw heating element and the second jaw including a second jaw heating element for converting electrical power to thermal heat energy, the energy source configured to supply a heater power signal having voltage and current to the first jaw heating element and the second jaw heating element, wherein the energy source comprises:

a controller programmed to control delivery of the heater power signal to the first jaw heating element and the second jaw heating element;

a first voltage sensor configured to sense the voltage of the heater power signal supplied to the first jaw heating element and configured to supply a first voltage sense signal in response;

a second voltage sensor configured to sense the voltage of the heater power signal supplied to the second jaw heating element and configured to supply a second voltage sense signal in response;

a first current sensor configured to sense the current of the heater power signal supplied to the first jaw heating element and configured to supply a first current sense signal in response;

a second current sensor configured to sense the current of the heater power signal supplied to the second jaw heating element and configured to supply a second current sense signal in response; and wherein:

the controller is programmed to calculate a first resistance value of the first jaw heating element and to compare the calculated first resistance value to a predetermined range of expected resistance values for the first jaw heating element based on the first voltage sense signal and the first current sense signal;

the controller is programmed to calculate a second resistance value of the second jaw heating element and to compare the calculated second resistance value to a predetermined range of expected resistance values for the second jaw heating element based on the second voltage sense signal and the second current sense signal;

the controller is programmed to respond to an activation signal, which is an indication of an execution of a thermal tissue operation, to supply the heater power signal as an operational heater power signal having sufficient energy to accomplish the thermal tissue operation;

the controller is programmed to respond to an absence of the activation signal between any subsequent thermal tissue operations to supply the heater power signal as a test heater power signal during a predetermined test interval, the test heater power signal having insufficient energy to accomplish a thermal tissue operation but having sufficient energy to create the first and second voltage sense signals and the first and second current sense signals to enable the controller to calculate the first and second resistance values of the first and second jaw heating elements;

the first voltage sensor and the first current sensor are configured to sense the voltage and current of the test heater power signal supplied to the first jaw heating element;

the second voltage sensor and the second current sensor are configured to sense the voltage and the current of the test heater power signal supplied to the second jaw heating element;

the controller is programmed to signal an error state and prevent further delivery of the operational heater power signals to the first and second jaw heating elements when at least one of the calculated first and second resistance values falls outside of the predetermined range of expected resistance values;

the controller comprises a control processor which is part of the energy source and a handpiece processor which is part of the handpiece; and

the handpiece processor is programmed to determine the voltage across the first and second jaw heating elements and to communicate the determined voltages to the control processor as the first and second voltage sense signals.

2. The thermal tissue operating system as defined in claim **1**, further comprising:

a first and second peak voltage detectors within the handpiece for sensing the voltage of the first and second jaw heating elements and supplying a peak voltage signal for each of the first and second jaw heating elements that indicate a peak magnitude of the sensed voltages across each of the first and second jaw heating elements during each test interval; and wherein:

the handpiece processor communicates the peak voltages to the control processor as the first and second voltage sense signals.

3. The thermal tissue operating system as defined in claim **1**, wherein:

each of the first and second peak voltage detectors is operative over a sample time interval to detect and hold the peak voltage signal of the sensed voltages over the sample time interval; and

the calculation of the first and second resistance values are performed using a maximum value of the voltage and current during each test interval.

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